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Cover Images: The front cover shows a couple all dressed up to watch an early television show, and probably excited to see such a large and clear image. The back cover shows two television test patterns that were transmitted after the TV shows were done for the day. The Indian-head test pattern was used for black-and-white transmissions and contained many alignment marks plus the interesting Indian head. The color test pattern was used for early analog color transmissions, and is not nearly as interesting to view. Front cover image: *Radio News* cover, August 1928. Back cover images: public domain.

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Foreword

Once again, we are fortunate to have many interesting, well-written, and well-researched articles recounting various events, people, companies, inventions, technologies, and milestones in the history of electronic communication. Below is a summary of each of the articles in the order that they appear.

- **Mike Molnar** describes the development of mechanical television. From its beginning, broadcast radio caught the public's attention, interest boomed, and the industry couldn't keep up. As radio programming matured, the obvious goal was to add sight to the sound. As experimenters began working with the available technology, every demonstration of their efforts would catch the public's attention. The statements about even a slight improvement were often followed with the phrase "Television is just around the corner." Soon it would become evident to all that the goal of commercial television service, using 1920s technology, was always just out of reach.

- **Jerry Proc** describes the history and technology of television development in Canada. For the most part, TV technology in Canada lagged behind that in the United States, so the development was different; Canada jumped into newer technology but at a later time; there was little experimentation with early forms of TV. Much of the population of Canada could watch TV stations that were on the United States/Canada border. The exception was in the French-speaking part of Canada, where residents fought for their French language.

- **Glenn Trischan** gives a history of Central Radio Laboratory. CRL provided a wide variety of discrete and innovative component products to the electronics industry as both original equipment manufacturer and as repair/substitution parts. While their products did not have prominent nameplate visibility, Centralab products could be found in virtually any electronic application requiring fixed or variable resistances or capacitors, as well as small inductances and switches. This story tells the brand's history and achievements from its founding to the days before WWII.

- **Eric Wenaas** discusses claims of the invention of radio regarding Oliver Lodge. Despite the lack of evidence, many recognized English authors believed Lodge when he claimed for the first time in 1925, 31 years after the lecture of August 1894, that he had sent and received telegraphic letters in Morse code at that meeting. In 2013, irrefutable evidence was found to the contrary in the form of sworn testimony by Lodge himself given to an examiner for the British House

of Commons in 1907, when Lodge admitted that he had not sent telegraphic messages or letters in 1894. Since this evidence was published in 2013, claims that Lodge sent telegraphic messages have been replaced with lesser claims that Lodge showed the "potential" for electromagnetic waves to be used for wireless signaling, and that Marconi used an "improved version of his equipment." This paper shows that neither of these claims have merit, and that Lodge's 1894 apparatus would not have allowed him to transmit telegraphic messages to any meaningful distance at any useful word rate.

- **Chuck Penson** presents a history of small multimeters, especially the Simpson type called Micro-Testers. The Simpson Electric Company is perhaps best known for its legendary Model 260 volt-ohm meter. In their early days, Simpson released a matched set of thirteen "pocket-sized," dedicated-purpose test meters it called Micro-Testers. Over the next decade, it modernized and expand the series, and competitors emerged. These instruments are simultaneously collectable and still surprisingly useful. This article explores the origins of the Micro-Testers, and the pocket-sized volt-ohm meters from which they evolved.

- **Bart Lee** describes long wave radio which was used extensively for reliable communications before the characteristics of shorter waves were discovered. Long wave radio was where it all started with communications by Guglielmo Marconi. Spark was first used to generate radio frequencies with high power, then arc and alternator, until tubes could be made for high power. When radio amateurs proved that short waves could be used for long-distance communications, and lower power and shorter antennas could be used, most of the communications shifted there. However, many uses remained for long wave communications, and more uses were discovered. Radio amateurs were again permitted to use the long waves for communications. Bart describes some of the excitement of finding strange activity on the long waves, and experiments with propagation.

We thank all of our authors for sharing their work with us. I thank each one of them for the cordial interactions we have had while preparing the manuscripts. I also want to thank our associate editor, Eric Wenaas, and our peer reviewers who have worked so hard and given so much time to review and edit these papers. Finally, I would like to thank Fiona Raven for the wonderful article layouts that we have come to expect each year—and especially for the original layouts on the covers of the *AWA Review*. Fiona's professional and creative work never ceases to amaze, and she makes all our authors look great.

Several years ago, the AWA created the Robert P. Murray Award in honor of Robert Murray, long-time *AWA Review* editor, and now Editor Emeritus, for

excellence in writing in the *AWA Review*. The fourth award was presented at the AWA conference in Rochester in 2021 to Michael Molnar. Congratulations to Mike for a job well done; we know he will continue to write high-quality articles in the future.

This is my third year as editor. I have greatly enjoyed this assignment and look forward to editing future editions. I hope my effort meets or exceeds the quality you have come to expect. My professional background as a systems engineer in major high-tech companies developing military weapons systems has well prepared me to pay attention to the detail needed and to meet the workload and scheduling requirements. My life-long amateur radio hobby and interest in all things electronic has provided a deep and yet broad background in radio communications and electronics of all kinds.

Tim Martin, WB2VVQ
Editor, *AWA Review*
Lee, MA

Tips for Authors

The *AWA Review* invites previously unpublished papers on electronic communication history and associated artifacts, with a focus on antique wireless. Papers will be peer-reviewed to verify factual content by peer reviewers whose identities will remain anonymous. This process gives the *AWA Review* credibility as a source of correct historical information. The papers will be edited to provide uniformity in style and layout among the articles. In general, shorter articles of six to eight pages (3,000 to 4,000 words) or less should be directed toward the *AWA Journal*, which is published quarterly. The *AWA Review* is intended for longer articles on the order of 6,000–9,000 words. Longer articles may be accepted with pre-approval by the editor, or then may be split into several parts.

The *AWA Review* will also publish Letters to the Editor as deemed appropriate. Letters should comment on articles published in the previous issue of the *AWA Review* or make brief comments on wireless history as it relates to one of the articles. Letters will not be peer-reviewed, but they may be edited. Text is limited to 400 words and no more than 10 references. The editor reserves the right to publish responses to letters.

It is strongly recommended that authors planning to prepare an article for the *AWA Review* send an abstract of approximately 200 words to the editor describing the subject and scope of the paper before writing the article, including an estimate of the number of words. It is never too early to submit an abstract. Space in the *AWA Review* is not unlimited, so both editors and authors alike need to have an estimate of the expected number of articles and number of pages for each article as soon as possible. The deadline for submissions of manuscripts in the next issue is February 1, 2023. Papers will be accepted after that, but papers submitted and accepted for publication before February 1 will have priority in the event that there is not space for all papers submitted.

Authors with an interesting story to tell should not be discouraged by a lack of writing experience or lack of knowledge about writing styles. The *AWA Review* will accept manuscripts in any prepared writing style. Editors will help inexperienced authors with paper organization, writing style, reference citations, and improvements in image quality. Edited manuscripts will be returned to the author along with comments from the editor and anonymous reviewers for the author's review and comment. The manuscript will then be set in its final form and sent back for one final review by the author. Normally, only one review of the layout will be accommodated.

To summarize, please submit completed manuscripts by February 1, 2023 (or earlier if possible) in three separate files:

1) A manuscript file without embedded figures or figure captions using Microsoft Word or other software that is compatible with Word. The manuscript should have a 200-word abstract, a main body with endnote citations and endnotes, acknowledgements, and several paragraphs summarizing the author's background. The author should also enclose a recent photograph focusing on the head and shoulders.

2) A figure folder, with one figure per file, with numbered figures and files that match the figure callouts, which must appear in at least one sentence of the manuscript text. Each figure file name should have several words of descriptor related to the image in addition to the figure number.

3) A figure caption file with a description of each figure and an attribution identifying its source. You may use the articles in this issue as a template for the style and format of your paper. For more information, consult the AWA website at http://www.antiquewireless.org/awa-review-submissions.html. Please feel free to contact me as editor for the *AWA Review* for any questions.

Timothy Martin, BE, ME, PE
AWA Review Editor for 2022
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When Television was Just Around the Corner

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Broadcast radio, from its beginning, caught the public's attention. From the first broadcasts in late 1920 through 1922, interest boomed and the industry couldn't keep up. As radio programming matured, the obvious goal was to add sight to the sounds coming through the ether. As experimenters began working with the available technology, every demonstration of their efforts would catch the public's attention. The statements describing even a slight improvement were often followed with the phrase, "Television is just around the corner." Soon it would become evident to all that the goal of commercial television service, using 1920s technology, was always out of reach.

Earliest Efforts

The history of many different technologies includes examples of long periods between a new understanding of science and that new knowledge resulting in a new technological innovation for the benefit of the average person. Electricity was studied for hundreds of years before Edison invented the electric light bulb and then still many more years before it was in the average home. Maxwell's equations were disclosed decades before the first radios, and Newton's laws were well known centuries before they were applied to guide astronauts to the moon. Similar events would take place before a family could gather around a box with a small glowing screen to be entertained by the image of Milton Berle in a dress or Jackie Gleason in a bus driver uniform. Mechanical television would be an important step toward making television into the broadcast and cable service we know today (Fig. 1).

In 2016, an Academy of Television Emmy Award was posthumously awarded to a mostly unknown Scottish inventor named Alexander Bain for inventing "the concept of scanning for image transmission."[1] The award was to honor his 1842 patent for a system to convert a still image into an electrical signal, send the signal some distance by wire, and reconstruct the image at that point. Although his system would be recognized as a facsimile system, it represented the first concept of what would

Fig. 1. The dream of television, circa 1900. (Author's collection)

require nearly a century of research and experimentation before the initiation of television broadcasting.[2] Researchers could now begin to have an understanding of the requirements for television.

There may have been different approaches to meet the requirements but these factors were necessary:

- Divide an image into a number of image components based on position in the image.
- Convert each component into an electrical signal that varies with corresponding intensity.
- Send the signals to another location, by wire or wireless.
- Convert the electrical signals back to image components; variations in light and dark.
- Reassemble the image components into the proper positions to create a visual image.
- Repeat these steps rapidly so the human eye sees a truly moving image.

All of these factors proved to be huge problems to solve. As decades passed, improvements in each area were incremental. Research from the earliest dates took place in Europe. As inventors worked on these issues, the first progress came with the transmission of still images by wire. It would take over 80 years before the first crude moving images could be transmitted and about another 15 years before an image of commercial value could be sent regularly. During the late 1930s, radio historian Archer Gleason wrote a summary of the television situation. He noted that the 1939 beginning of commercial broadcasting marked another step in the most intensive and expensive campaign of scientific research in the history of mankind.[3] He also noted that one of the most intriguing problems affecting radio sales in the 1930s was caused by "television—that elusive sprite that for a full decade has been *just around the corner.*"[4]

Incremental Improvements

Selenium

The chemical element selenium was first discovered in 1817 by Berzelius, a Swedish chemist, when it was extracted from metal ore. Some 20 years later, as more of selenium's properties were discovered, it found use in telegraphic equipment, due to its property of high resistance to an electrical current. Soon a technician named May, working at the Atlantic cable station in Valentia on the west coast of Ireland, noticed a change in the electrical characteristics of the device. After several occurrences, he came to realize that when exposed to light, the electrical resistance of the selenium was reduced.

This information was passed on for scientific investigation, and Willoughby Smith conducted experiments to quantify the behavior of selenium.[5] This sensitivity to light answered the problem confronted by researchers looking for ways to convert the light reflected off an object into an electrical signal. The selenium detector, when placed in a circuit as a photoresistor, in series with an electrical source, acted as a valve allowing more current to pass when struck by more intense light. Although this invention came decades

before the carbon button microphone, the performance is similar. As more pressure from sound waves strike a carbon button, its resistance drops allowing more current from the local battery to pass. The light hitting the selenium cell in circuit with a local battery can be understood as a microphone for light.

Although this discovery would seem like the perfect solution for a television system, it was not.

Investigation would soon reveal that the time required for selenium to respond to light and to recover from the exposure to light were not linear or symmetrical (Fig. 2). For the number of pictures per second to create a television picture with acceptable flicker, selenium's response time was too slow. The recovery time, as shown on the graph, is notably slower than the light response time. The selenium cell did find use in converting a still image into an electrical signal. By passing the cell over a segment of the light reflected off of an image, the electrical signal that was produced could be sent by wire to a location where the image was reproduced, one segment at a time. This was done by a number of inventors, often with remarkably good results.

Nineteenth-Century Progress

Nineteenth-century devices to produce an electric image of an object often included a cylinder to hold the photographic image. A light source was focused on a small part of the picture and the light, either reflected or passed through the photograph, was reflected to a selenium cell detector. The cylinder moved the photograph in much the same method as an Edison cylinder phonograph moved the audio recording. As the cylinder with the photograph is rotated, it is scanned vertically. The cylinder is mounted to a spring motor or other drive that moves the cylinder by turning a screw that horizontally scans the photograph in a spiral (Fig. 3). This action slowly scans the entire photograph and the output of the selenium cell is sent to a receiver with a modulated light source

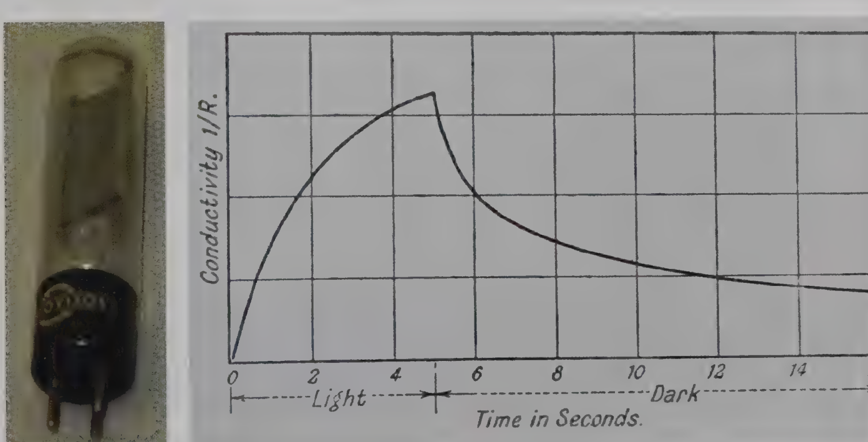


Fig. 2. Selenium cell and response curve. (E. T. Larner, *Practical Television*, p. 71)

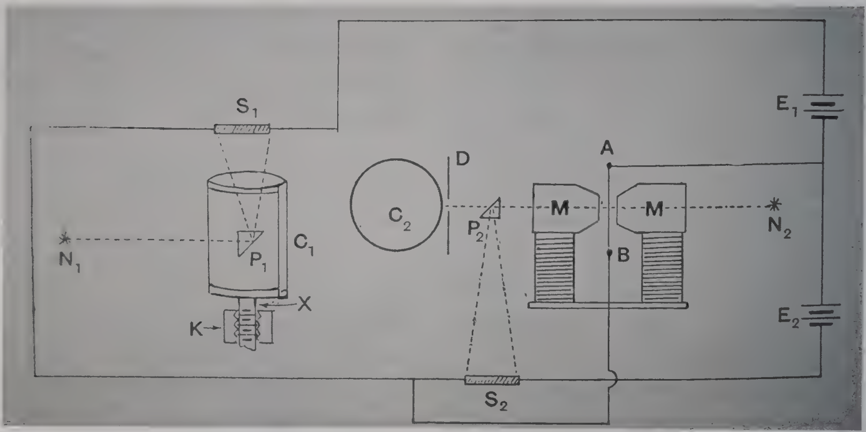


Fig. 3. Professor Korn's compensated selenium system. A photograph placed on cylinder C_1 is scanned by light from N_1 and the signal it generates is used to deflect wire A-B. This controls the amount of light from N_2 passing through M to expose the photographic film on cylinder C_2. (T. Thorne Baker, *Wireless Pictures and Television*, p. 72)

that exposes photographic film mounted to a similar cylinder assembly synchronized with the transmitting cylinder.[6]

Creating a modulated light source to expose the film was a difficult task. One method was to use either a mirror or string galvanometer. The galvanometer was constructed in a manner that light could be passed between the coils and be blocked by a string that when deflected by the feeble current from the transmitter would move the string to allow a proportional amount of light through to expose the photographic film. Similar arrangements could be made with a mirror assembly to be shifted by the current allowing light to pass through an opening.

Different inventors made different advances. A professor, Arthur Korn, devised a system with two specially prepared selenium cells in a bridge circuit arranged so that the non-linear effects in one cell could be compensated for by different response characteristics of the second cell. That gave improved results that allowed Korn to use his compensated selenium circuit to provide a commercial service using telephone circuits. As can be seen in the image (Fig. 4), the transmitter and receiver were synchronized by voice command on another telephone line.

Other inventors including Belin, Thorne, Baker, and later Francis Jenkins and Ranger in the United States, would produce still image systems. There was commercial demand for the transmission of pictures of important people and events as well as documents and fingerprints that could now be accomplished in minutes. As radio development progressed, sending still images by radio became an important feature for companies like RCA to add radio pictures to their Radiogram service. Another result

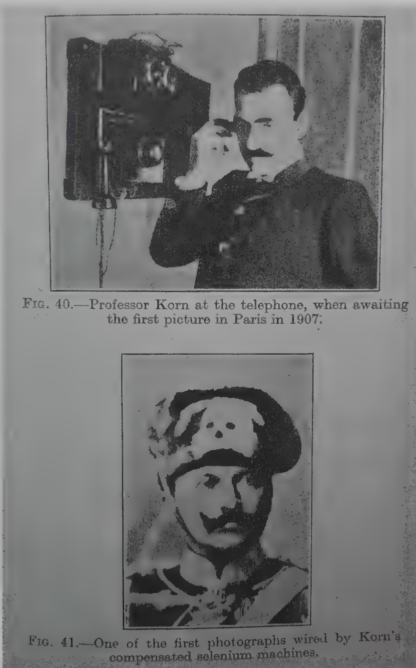


Fig. 4. Top: Professor Korn at the telephone awaiting the first picture in Paris in 1907. Bottom: One of the first photographs wired by Korn's compensated selenium machines. (T. Thorne Baker, *Wireless Pictures and Television,* p. 81)

of this work with still pictures came the realization of the difficult challenges ahead for television.

Nipkow Disc

The next major development in the effort to send a moving image by an electrical signal came from German inventor Paul Nipkow (1860 to 1940). His invention (Fig. 5) involves a spinning disc perforated by a spiral of holes. The number of holes in the spiral is equal to the number of scanning lines in the image. The distance of the last hole to the edge of the disc, minus the distance of the first hole from the edge of the disc, determines the height of the scanning area. The distance between the start of the first hole to the start of the second determines the width of the image and the number of revolutions per second equals the number of frames per second. Any device used to detect the light passing through the holes varies with the amount of light reflected from the object being scanned. Thus, a

PAUL NIPKOW and his famous SCANNING DISC

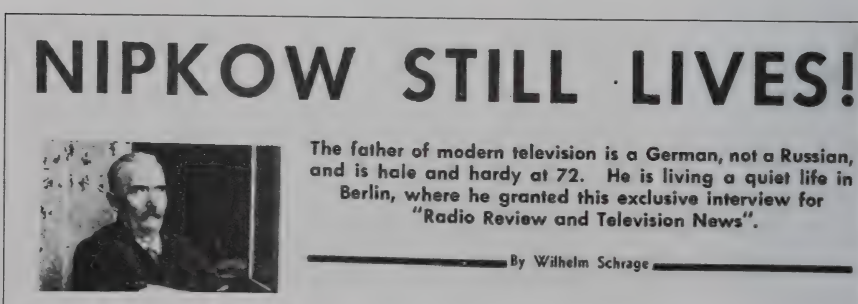
Fig. 5. Paul Nipkow and a Nipkow disc. (Raymond F. Yates, *New Television – The Magic Screen,* p. 22)

device synchronized with another disc at the same starting point and a light source that varies in the same proportion gives the viewer the ability to see an image of a moving object from a distance… television.[7]

In an interview late in his life (Fig. 6), Nipkow, now 72 years old, spoke about Christmas Eve 1883, when a poor and hungry inventor was working on ideas for what he called his favorite problem, the "Televisor." Then the moment came when he realized this invention could work. "I jumped up"' he said, "and danced around the room like one possessed, so that my landlady came into my room full of terror, fearing that something had happened to me. Actually, something had happened to me, but something delightful, something that made the hitherto so gloomy Christmas a brilliant festival, the most beautiful Christmas festival I can remember. Suddenly my stomach no longer called for food, I was gay, rich, and happy."[8]

When he was asked why he didn't pursue his experiments and produce a working model, Nipkow had a simple answer, "I was so poor I had to let my patent lapse after a year. I did not even have the money to continue my study, to say nothing of the money for making experiments." Nipkow did go on to finish his education and became an engineer for the Signalbau Company, retiring after 33 years as the chief engineer.[9] Not forgetting his old invention, he did continue work on his disc and filed two patents in his later years.[10]

Many others did take up his invention in both the original and improved forms. There were typically two ways to transmit the image using a Nipkow disc. The first was to simply use a lens to focus the light from an image onto the scanning area of the disc. The number of holes spaced over one revolution determines the number of lines in the image. As the disc makes each revolution, each passing hole sends the light from a corresponding line of light from the object to some device to convert the varying intensity of light into a similarly varying electrical signal. The process is repeated for each passing hole, scanning the light from the object one line at a time until a full revolution of the disc is accomplished, thus completing a frame.


NIPKOW STILL LIVES!

The father of modern television is a German, not a Russian, and is hale and hardy at 72. He is living a quiet life in Berlin, where he granted this exclusive interview for "Radio Review and Television News".

By Wilhelm Schrage

Fig. 6. Paul Nipkow interviewed at age 72. (Wilhelm Schrage, "Nipkow Lives," *Radio Review and Television News*, Jan–Feb 1933, p. 290)

As the rotations continue, frame after frame of the object is acquired, reaching a number of frames per second corresponding to the speed of the motor spinning the disc. This method is referred to as direct scanning. The major problem with this method of scanning is caused by the small amount of light passing to the detector. As an example, a disc with an image area only one inch tall requires that each hole cannot exceed one-thirtieth of an inch in diameter. At the speed at which these tiny holes spin past, little light is left for the detector.

The second method is called spot scanning or flying-spot scanning. In this method, credited to the Swedish inventor A. Ekstrom in 1910, the same scanning disc can be used.[11] The light for the object to be scanned is produced by a high-intensity lamp, typically an arc light. The arc light creates a high output from a high voltage arc between two closely spaced rods. As the light is produced, the rods need to be continually advanced towards each other as the carbon rods burn away. This light is then focused on the imaging area of the disc and onto the object to be televised. In a darkened room, the light from the scanner will appear to be bathing the object in a steady light. Detectors can be placed around the object and pick up all of the reflected light. What a fast-responding detector sees and responds to, is only the single spot of light flying over the object. This is an effective method of scanning as multiple detectors can be placed around the object to increase the signal strength. The arc light produces a very high-intensity light but still the amount of light for the detectors is small when we consider how fast the spot needs to pass over the detector to produce a moving image for the human eye.

To reproduce the scanned image, the modulated signal from the light detector is sent to a modulated light source. That light then passes through an identical disc with the same number of holes in the spiral and in synchronized rotation speed with the transmitter to display the image. Various schemes were tried to provide a source of light that could be varied to match the output of the detector.

Inherent Problems with the Nipkow Disc

There are several problems associated with the Nipkow disc. The first is quickly noticed when first viewing an image. Because the radius from the center of the disc to the first hole in the spiral is longer than the radius from the center to the last hole in the spiral, the resulting image frame is not rectangular but has a keystone shape. The width at the top of the image is noticeably greater than the width at the bottom of the image. Typically, discs would have 30 lines and an image area around 1½ by 2 inches, and would be 16 inches in diameter. To increase the size of the image on the disc to 4 inches by 5 inches with 100 lines would increase the size of the disc to a full 12 feet in diameter.[12] To use an image at a rate of 20 frames per second requires a huge disc moving at 1200 RPM.[13] The only practical method of increasing the size of the image was with a magnifier.

The small amount of light that passes through the disc at any instant is a problem for the available detectors. If, for example, the disc was to have 24 lines in an image, meaning 24 one millimeter holes in the spiral, and an image area of 24 mm by 24 mm, the image area is 576 sq. mm, so that only 1/576 of the available light passes through the disc at any instant. If we wanted to improve the resolution to 48 lines with one millimeter holes, the amount passing through the disc at any one instant is 1/2304 of the available light. The typical frame rate for a moving image was 15 frames per second, because any increase in the frame rate also reduces the instantaneous light available to the detector.

The precise machining of a disc is a difficult procedure. The position of the holes in the spiral must be precisely machined. A small amount of overlapping of each trace will cause brighter stripes in an image and underlapping causes dark stripes. One method to increase the amount of light was to have a spiral of square holes over round holes. This would increase the amount of light by about 20% but that precise machining was not a job for amateurs or small operations. A more sensitive detector, the photoelectric cell, was needed to make the Nipkow disc practical for scanning images for television.

The Photoelectric Cell

The discovery that led to this next advance had nothing to do with television or producing an electrical image. Rather, it came as part of the effort to understand radio waves. Years after James Clerk Maxwell published his theories of electromagnetic radiation, they remained just theories. It took the work of Heinrich Hertz to prove them true. He did this by producing a spark in one part of his lab and found that he could receive a spark between two contacts across the room. Hertz performed many experiments to learn the characteristics of this phenomenon. To see if he could receive a stronger spark, he placed the spark contacts within a glass shield to block any air currents and improve the spark. He was surprised to find that when he shielded the contacts, he only diminished the spark. That changed when he used a quartz shield and he found that the spark was not diminished. This led him to believe that light, particularly ultraviolet light, was increasing the passage of current.[14]

This started the investigation of many scientists to find substances that when struck by light can produce a current between the substance and a nearby conductor with an applied positive voltage. This led to the development of the photoelectric cell or photocell. This should not be confused with the selenium cell which is also referred to as a photocell. While the photoelectric cell actually produces a minute current when struck by light, the selenium cell changes its resistance to electrical current. The characteristics of the photocell, over the selenium cell, are much more suitable for television work. It is fast to respond to variations in light and the response is also very linear (Fig. 7). There always seem to be downsides that cause engineers to find solutions, and in the case of the photocell,

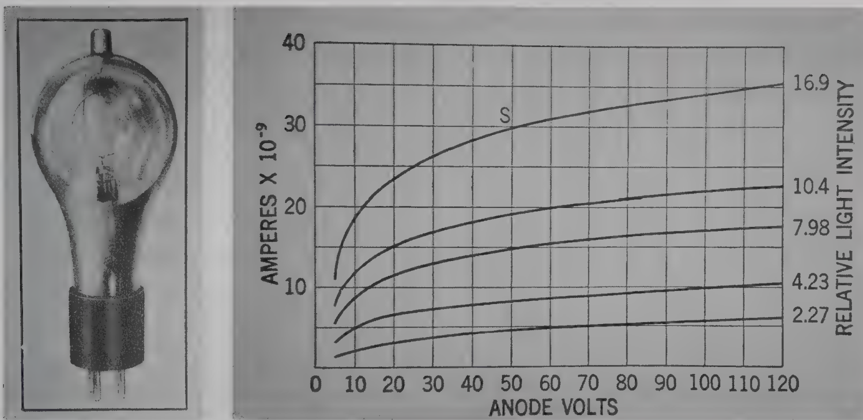


Fig. 7. Conventional 1930s photocell and response curve. (Raymond Francis Yates, *A B C of Television*, p. 73)

the problem was the small amount of current being produced. Many photocells had an output of less than 100 microamps. Its effective use in television would require the amplification by the new triode (Audion) vacuum tubes that were being introduced.

These devices quickly became the standard method of detecting the scanned light. Various chemical compounds were tried to produce the highest output. They were produced by many companies in many configurations.

Neon Glow Lamp

After many years of research and development, the search for a method of modulating light for a television display yielded poor results. The requirements for a television display are demanding. The light source must be able to respond quickly, in a linear response, and yield an image bright enough for the viewer. The answer came in a special neon lamp (or tube). These lamps relate to the mechanical television as the loudspeaker relates to the radio.[15]

The lamp is constructed with two parallel plates in a glass envelope with neon gas at low pressure (Fig. 8). When a DC potential, typically 180 volts, is applied to the plates, and current is raised to 5 ma, one plate will begin a steady glow. As the current is increased, the brightness will

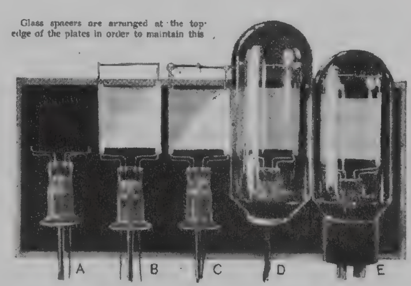


Fig. 8. The steps in the assembly of a neon glow lamp or tube. A: Glass stem wire supports, ready for the plates. B: Plates mounted in position. C: Plates completely assembled, with top wire supports. D: Tube ready for evacuation. E: Complete tube ready to work. (D. E. Replogle, "The Neon Tube-Television's Loud Speaker," *Radio News*, Nov. 1928, p. 427)

increase linearly to a maximum at 20 ma. Increasing the current above 20 ma would damage the lamp or decrease its life. Construction of the lamp requires sturdy support of the plates that need to remain steady, as the lamp is mounted near the vibrations of the spinning disc and motor. The surface area of a 2 inch square plate is only useful in the center 1½ inch square, as the light intensity falls off near the edge.[16]

As the television viewer looks through a magnifier at the spinning disc and sees the flickering image, it is not apparent that the light is coming from the bright plates of the glow lamp. The intensity of the light from the entire lamp, at any instant, is at the intensity for the picture element being scanned. The disc and lamp are synchronized so that the right intensity of light passes through that tiny hole at the instant it is in the right position.

Early Successes

Using the technology available in the early 1920s, two independent inventors are credited with creating the first television images. There is some disagreement over what can be called the first real television images, as the very first images were crude and some had no real greyscale and were really shadowgraphs of images. A claim for being first came from a Scotsman working in London, John Logie Baird. Although he used spinning discs, the apparatus hardly looked like the simple Nipkow disc.

John Logie Baird, 1888–1946

John Logie Baird was born in Glasgow, Scotland, the son of a Presbyterian minister. His childhood was marked by illnesses and difficult years in different schools. When the first world war began, Baird went to enlist but his poor health kept him out of the military. He was given a job to maintain an electric power station, which he did for some time. He had always been a tinkerer and inventor and one of his experiments, which temporarily knocked out the electrical power system, quickly found Baird out of a job. He did continue inventing and was starting to have some success when he suffered a complete physical and mental breakdown. One of Baird's biographers, Alfred Dinsdale finally states, "We will not trace his subsequent activities, suffice it to say that they form an amazing record of enterprise and ability dogged by continual ill health and recurrent illnesses." He goes on to say, "in 1923, he found himself compelled through ill health to abandon all business and lead the life of a recluse."[17]

So, what should someone in this physical condition, with no money, but filled with an inventive spirit do? Baird decided to invent television, something no one else had ever been able to do. He believed that with the development of selenium cells, the Nipkow disc, and other devices, the time was right for an inventor to assemble all of these pieces and produce a real television image. His operation was as crude a low-budget operation as you could imagine, and as legend has it, working in an attic and using packing crates, biscuit tins, and whatever he could

scrounge to build a television system. In April of 1925 he was able to demonstrate a crude shadowgraph image and used that success to raise some funding.

His first system to present a true image of an object used an apparatus very different than the simple Nipkow disc. The light reflected from a brightly lit object first passed through a disc with 16 lenses in a spiral pattern. That light was passed through a serrated disc rotating at a high speed which chopped the light into pulses that were better suited to Baird's light sensor. The next disc, rotating at a slower speed, had a spiral cut out. This resulted in the image projected by each lens being pulsed and then scanned by the spiral before striking the detector.

At the receiver, the same optical system was in place, synchronized to the transmitter. Instead of a light detector, a neon lamp flickered to match the transmitter signal. This passed through the spiral and then through the lens disc. This image was focused on the rear of a ground glass screen and the viewer on the other side, with the aid of their persistence of vision, saw the image of the transmitted object.

On January 27, 1926, in his little attic laboratory, Baird gave the first demonstration of his television system (Fig. 9). Observers noted that it was a true image, that the object was recognizable, and there were visible gradations of light and shade (Fig. 10). Baird improved his "Televisor" and made many public demonstrations, including a transatlantic broadcast, to gain publicity and investors. He would periodically announce

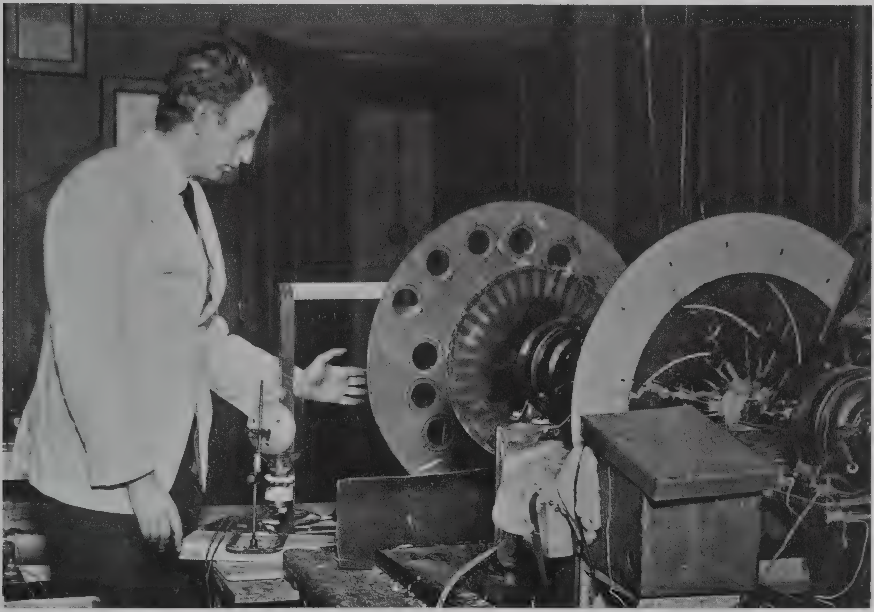


Fig. 9. John Logie Baird with his early television apparatus. (Sydney A. Moseley and Herbert McKay, *Television – A Guide for the Amateur,* plate 1, frontispiece)

many firsts. His stereovision invention gave a 3D image and his noctovision worked with infrared light. He produced color images as well as recorded television images on phonograph records. None of these or other innovations were incorporated into a television service, but he did begin broadcasting on a regular basis. As time passed, his company grew and Baird, once the lone inventor, was forced to accept that, in order to compete, the work of others had to be used by his company. Soon this competition forced Baird's television company to begin work in electronic television.

Fig. 10. Photo of the first television image ever taken. This is an actual untouched photo of the image as it appeared on the screen of the first Televisor. (Sydney A. Moseley and H. J. Barton Chapple, *Television Today & Tomorrow*, p. 49)

Charles Francis Jenkins, 1867–1934

Better known as C. Francis Jenkins, he was a famous inventor long before his success with a television system. In the 1890s his interest in photography led him to investigate a system for projecting moving images onto a screen. His invention was the Phantascope, patented in 1894, (Fig. 11) and he is credited with giving the first moving picture demonstration to an audience. He sold his patent rights to a partner and the device was incorporated into the Vitaphone. It was the Vitaphone that was sold to

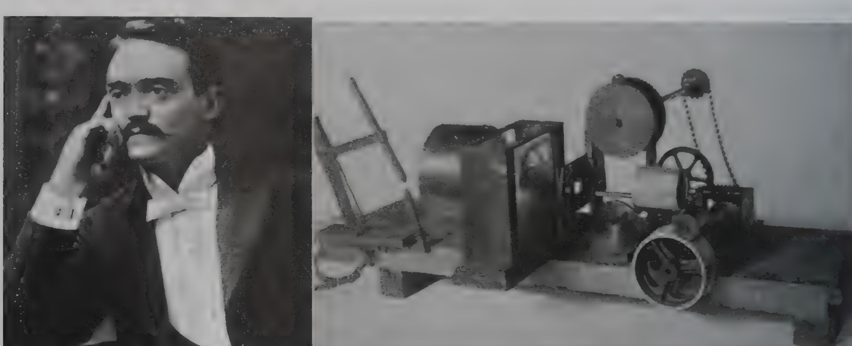


Fig. 11. C. Francis Jenkins and the Phantoscope. (Soterios Gardiakos, *From the Phantoscope to the Vitascope*, pp. 10, 20)

Thomas Edison to become part of his Kinetoscope movie projector. Jenkins's inventing didn't slow down and he would be credited with over 400 patents in his lifetime. He is also credited with building the first automobile with the engine in the front. Jenkins formed Jenkins Laboratories Inc. and set up shop in Washington, DC.

He would document his work in books he published through his company. He was very clear in defining what the different devices were called and what they could do. His definition of television did not agree with the general usage of the terms at the time:

- Radio Pictures: Still images transmitted by radio.
- Radio Vision: Images of moving objects transmitted by radio.
- Radio Movies: Moving images captured on film and transmitted by radio.
- Television: Moving images transmitted by wire.

One of the first devices Jenkins designed for scanning an image was named the prismatic ring (Fig. 12). It consists of a glass disc that is flat except for the outer few inches. This outer area starts out narrow at zero degrees but as the disc rotates it gradually widens until it reaches 360 degrees. This creates a prism with an increasing angle as the rotation increases. The result is that a beam of light passing through will be deflected at an increasing angle as the rotation increases. After 360 degrees the deflected beam returns to the starting point. By using two discs slightly overlapping each other, with the first mounted to pass light through the top, and the second mounted to pass light through the side, both horizontal and vertical scanning are accomplished.[18]

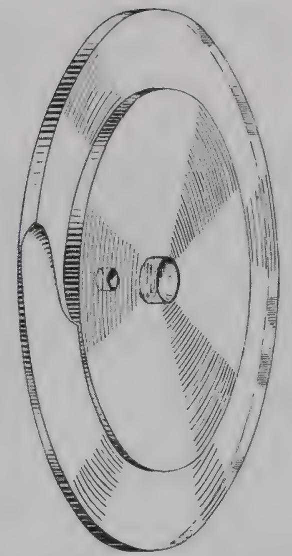


Fig. 12. C. Francis Jenkins prismatic disc. (Alfred Dinsdale, *Television, Seeing by Wire or Wireless*, p. 36)

His initial work involved radio pictures and the results were impressive (Fig. 13). Jenkins' first public television (radiovision) demonstration came some months after Baird's demonstration. He used the prismatic rings as a scanner, and his receiver used rings and a lens disc. After the demonstration, he developed a receiver showing some new approaches compared to the spinning Nipkow disc (Fig. 14). This device used a rotating drum, with a spiral of holes, mounted laying on its side and attached to a motor

shaft. A special neon glow lamp with four individual sections was mounted in the center of the drum. Light was directed from the lamp to the holes through quartz rods which acted as light pipes to the holes in the spiral (Fig. 15). The appropriate section of the lamp was triggered by electrical contacts rotating with the drum. The image was projected up from the drum and into a mirror that directed the image to the viewer through a magnifier.[19] Although a sophisticated and modernistic device for its time, no evidence exists showing these were ever sold to the public (Fig. 16).

Fig. 13. Sample image of Jenkins radio picture. (C. Francis Jenkins, *Vision by Radio, Radio Photographs, Radio Photograms*, p.19)

Jenkins was one of the first to begin regular broadcasting. Station W3XK was constructed and broadcast from Wheaton, MD. At that time, the ability to broadcast an image in halftones and clear detail was out of reach with the light detection available. Another method of transmitting moving images was called shadowgraphs. The scenes were black silhouettes moving in front of a white backlit screen (Fig. 17). The simple "Radiomovies" with light projecting directly toward the detector,

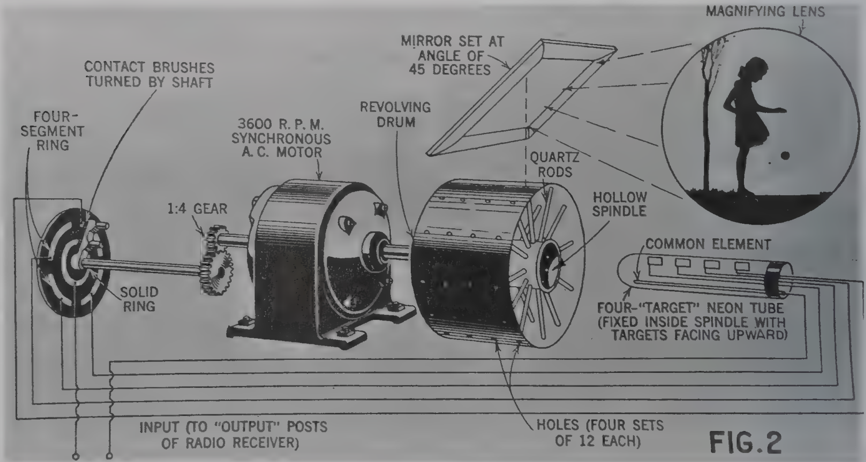


Fig. 14. The Jenkins drum receiver diagram. (*Radio News*, Aug. 1928, p. 117)

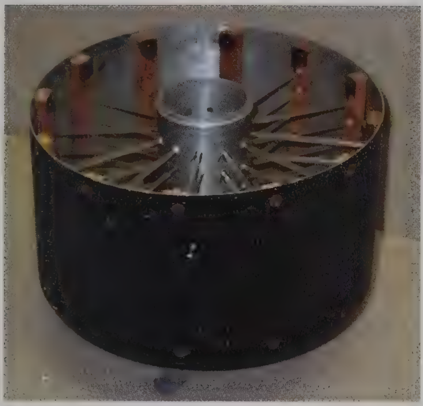


Fig. 15. Jenkins scanning drum with quartz rods. (Press release photo, author's collection)

Fig. 16. C. Francis Jenkins viewing the television image. (C. Francis Jenkins, *Radiomovies, Radiovision, Television*, p. 62)

Fig. 17. Jenkins directs broadcasting a shadowgraph. (Movie press release photo, author's collection)

and with images only changing from black to white, were more suitable for the light detection by a selenium cell.[20] Very short programs with very limited story content had little entertainment value.

AT&T and Bell Labs

The laboratories financed by the phone companies enjoyed the benefit of funding for research that may not pay an immediate or medium-term return on the investment. Unlike the return on a device such as the vacuum tube or transistor, the research on television for a video telephone service was certainly betting on a long shot. The principal researcher in this effort was Dr. Herbert E. Ives and he did produce some impressive results. Work began in 1923 on sending photographs that could provide a service with a possible financial return. Sending photos for news services, legal documents, and other needs could provide additional business for long-distance phone service. Also, in order to gain positive publicity showing the good use of the fees paid by telephone users, many public demonstrations were made of these technological developments. The reasons given for funding Ives' research on television was "to keep the Bell System abreast of the general advances in the art of television and to perform such work in connection with new ideas and suggestions as to methods, apparatus, and field of service, as may be necessary to properly evaluate them."[21] Ives was given what was termed a "sizable staff," and over the period of this research, it was estimated to have cost some $250,000.[22]

Devices that were built for the transmission of still images over phone lines gave excellent results (Fig. 18), and a service was opened for sending facsimiles across the country for news services and parties needing to send documents, photos, or legal papers. Over time, this returned the financial investment in the television research. The announcement of the first transmission of still images from Cleveland to New York included excellent sample images. The time to make the transmission of these quality images was quite long; sending 15 photographs took two hours. This would certainly demonstrate how far away a quality television system was from being practical when many of these images would have to be transmitted every second.

PICTURES TRANSMITTED BY TELEPHONE WIRE FOR FIRST TIME

TRANSMISSION OF PHOTOGRAPHS OVER A LONG DISTANCE TELEPHONE WIRE WAS DEMONSTRATED BY ENGINEERS OF THE AMERICAN TELEPHONE AND TELEGRAPH COMPANY THE OTHER DAY WHEN PICTURES OF PRESIDENT COOLIDGE, NEWS PICTURES AND STREET SCENES WERE SENT FROM CLEVELAND TO NEW YORK. FIFTEEN PHOTOGRAPHS WERE SENT IN TWO HOURS. THE PHOTO ABOVE IS A REPRODUCTION OF ONE OF THOSE SENT SHOWING PRESIDENT AND MRS. COOLIDGE AT THE FUNERAL OF THE LATE PRESIDENT HARDING. SO FAITHFUL WAS THE TRANSMISSION THAT EVEN THE TINY SPOTS ON MRS. COOLIDGE'S VEIL WERE RECORDED ACCURATELY.
B 5-21-24

Fig. 18. Press release of President and Mrs. Coolidge. (Still image sent by wire by AT&T, with original notes, author's collection)

The television systems built by Ives fit into two types. The first type is a two-way picturephone conversation with small screens for viewing and each of the parties scanned (Fig. 19). His system used a flying-spot scanner and photocells to produce the image. Bell Labs developed a much-improved photocell, as they learned that a thin coating of the photoemissive compound gave a higher output current. Still, two or more photocells and amplification were needed to send the signal down the phone line.[23]

The second television system produced by Ives included a unique large display, two feet by three feet. It used a single long neon tube curved in a pattern to fill the rectangular field (Fig. 20). One of the two elements of the neon tube was a coil winding through the length of the tube. The second element to light each segment of the tube was outside of the glass. Each of these metal strips was wired to a wheel with contacts in the order of the rows and columns related to the neon tubes. A contactor was attached to an arm rotated by a motor sending the image signal in sequence to each image element in the display (Fig. 21).[24]

The first public display on April 7, 1927, included a presentation by Herbert Hoover, then secretary of commerce (Fig. 22). Television over wire circuits was demonstrated between New York City and Washington, DC, and television over radio was sent from station 3XN, an AT&T transmitter in Whippany, NJ, to New York City. The radio transmission included an entertainment program.[25] Reviews of the demonstration remarked on a lack of detail when the subject was

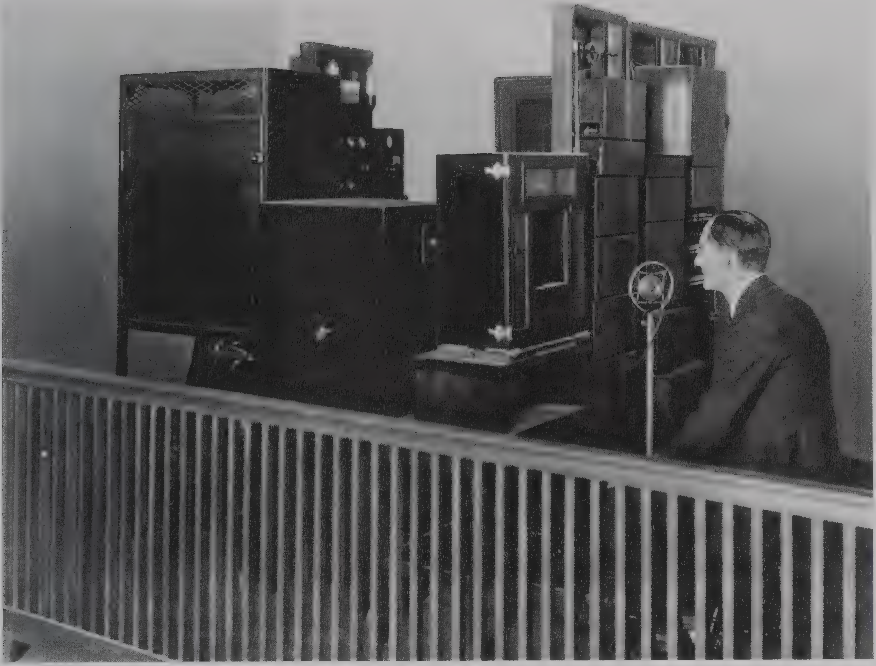


Fig. 19. Press release photo of testing the AT&T two-way television phone system. (Author's collection)

Fig. 20. AT&Ts Large Grid Screen television display. Top left: Long single neon tube. Top right: Enlarged view of electrodes wrapped around tube. Bottom: Individual wires for each electrode connected to rotary contact wheel. (John Mills, *Through Electrical Eyes*, p. 20)

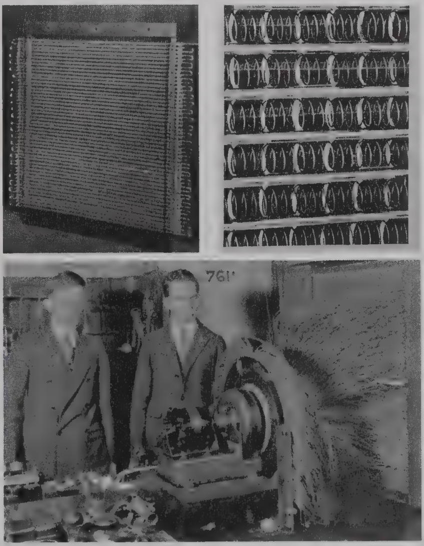


Fig. 21. Components of the Large Grid Screen display. (John Mills, *Through Electrical Eyes*, pp. 26, 27, 33)

PRICE THREE CENTS

Television Now Reality; Device Demonstrated

Secretary Hoover First to Make Use of Latest Scientific Achievement

Image of Speaker is Carried by Phone and Radio.

RESULT OF YEARS OF EXPERIMENT

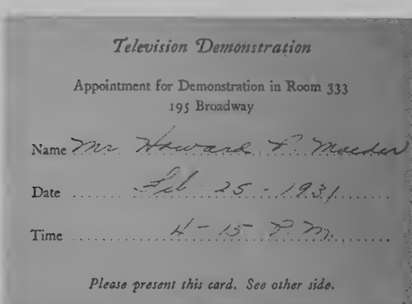
New York-Washington Tests Complete Success.

Secretary of Commerce Herbert Hoover, Speech Transmitted by wire and radio, April 7, 1927

Fig. 22. Secretary Hoover's television inauguration speech. (*Troy Record*, Troy, NY, and author's collection)

holding still and the viewer had a somewhat better feel for what they were seeing when there was some movement.

In 1930 the equipment was set up for a public demonstration of a two-way video phone service, now called Ikonophones. The demonstrations took place at two locations, 2 miles apart in Manhattan. Two guests would be invited and had 2 minutes to see and speak to each other (Fig. 23). This unit was improved from the original 50-line system to 72 lines.[26]



Television Demonstration

Appointment for Demonstration in Room 333
195 Broadway

Name Mr. Howard F. Maeder

Date Feb. 25 - 1931

Time 4 - 15 P.M.

Please present this card. See other side.

Fig. 23. AT&T Invitation to try the television phone. (Early Television Foundation, Hilliard, Ohio, website)

Ernst Alexanderson and General Electric

Ernst F. Alexanderson was born in Upsala, Sweden, to an upper-class family. The son of a professor, he had the opportunity to have a solid education in engineering. After completing his studies, he decided to emigrate to the United States. This is where he, and many Swedes at that time, saw the best opportunities for a good career in the country where big things can still happen. After arriving in New York City, he decided to travel to Schenectady, New York, to the General Electric Company, where he hoped to meet a scientist he admired, Charles Proteus Steinmetz. He hoped that he could meet Steinmetz, impress him with his knowledge of Steinmetz's work, and be offered a job at General Electric.

He found where Steinmetz lived, knocked on the door, and got a job in the drafting department. Soon he earned a transfer to the GE Testing Department, where new engineers were apprenticed into GE methods and products.[27]

By demonstrating his abilities, he was soon given new and important assignments. One of these assignments would change his life.

Perhaps the top U.S. scientist/engineer working on wireless telegraphy around 1900 was Reginald Fessenden. He had been working on a method to change wireless transmissions from the blast of spark energy that occurs when the contacts on a telegraph key are closed, to a transmission of continuous waves of radio energy that can be modulated to send information. With a system like this, he would be able to transmit by Morse code or by voice. Fessenden had a plan to build an alternator that could produce alternating current at a high enough frequency to be a continuous wave radio signal.

Fessenden's lab was not set up to take on that kind of project, so he took his plan to a company already producing alternators for supplying electric power, General Electric. The man given the assignment to develop such a machine was Ernst Alexanderson.[28]

His work was so successful that these alternators for producing radio waves became known, worldwide, as Alexanderson Alternators. Step by step, GE produced models with higher output and at higher frequency. Fessenden received the alternators to complete his order, and GE had a new product for the wireless industry. Before WWI ended, two 200 kilowatt Alexanderson Alternators were installed in New Brunswick, NJ, to keep the United States in contact with Europe at this critical time. Ernst Alexanderson was now a world-famous inventor.[29]

At the General Electric Research Department in the early 20th century, a scientist such as Alexanderson could suggest an area of research that may not have an immediate goal of creating revenue, but could have positive results sometime in the future. In the mid-1920s, after Alexanderson saw the positive results that the work of Baird and Jenkins had produced, he saw it was time for GE to perform a feasibility study to see if television would have the possibility of becoming as big a product for GE as radio had become. If these small company inventors could have good results, the effort produced by a large corporation like GE should be that much greater. Alexanderson would lead this research team himself.

Alexanderson and his Engineers Examine Mechanical Television Technology

It is most likely that Alexanderson's contribution was not as hands-on as other inventors. Edith Norland, Alexanderson's daughter, describes him as the typical absent-minded professor, one who didn't know how to operate the can opener. She related how he could pass by her on the street, not recognizing her as he was lost in thought. One time while demonstrating the television receiver at his home, he could not get it to come on. His wife kindly mentioned it needed to be plugged in for power.[30]

The research team began work in 1923. Starting with the technology available at the time, there were incremental improvements to the different systems then in use. When questioned about this

line of research, when a scientific look at the potential of mechanical television did not look favorable, Alexanderson replied that this was what they had to work with until something more promising came along. Research was also progressing in facsimile transmission which was showing more promise. Alexanderson's analysis of the requirements for quality television included his conclusion that the bandwidth requirements were greater than others believed at the time. He correctly concluded that a television service would have to be in the shortwave and ultra-shortwave bands.

There are a number of references to Alexanderson communicating to management and the GE patent department. The improvements made by the team were patented when possible and Alexanderson and GE were pleased that the company was building up a patent position in television and facsimile. A strong patent position was important, because they eventually wanted to build systems for transmission of images to a home receiver, transmitters for live outdoor events, and televised a live play. There was also development of a large screen display for use in a theatre.

Alexanderson had a photogenic family. They are all dressed up nicely and gathered together to watch his 48-line TV in Fig. 24. Alexanderson is holding a switch so that he can interrupt power to the disc motor which could be used for synchronization. Behind him is a Radiola 28.

The mirror drum was invented in 1899 by Lazare Weiller.[31] It consisted of a cylindrical drum mounted horizontally attached to a motor shaft (Fig. 25). Rectangular mirrors were mounted in a series surrounding the drum. The mirrors were mounted at an angle increasing slightly for each step progressing around the drum. As the drum rotated, a beam of light was deflected horizontally by the varying mounting angle of the mirrors. The vertical deflection was accomplished by the rotation of the drum.[32]

On a trip to Europe, Alexanderson met with other television researchers. Among others, he met with Augustus Karolus. He was utilizing the mirror drum in conjunction with a device using a Kerr cell as a light modulator (Fig. 26). Researchers had learned that polarized light passing through a container of certain chemical mixtures, with a DC voltage applied to the solution, can produce a shift in the angle of polarization corresponding to the amount of voltage applied. It was long known that if light is passed through a horizontal

Fig. 24. Alexanderson and family enjoying television (synchronizer in hand). (*Popular Mechanics*, Apr. 1928, cover)

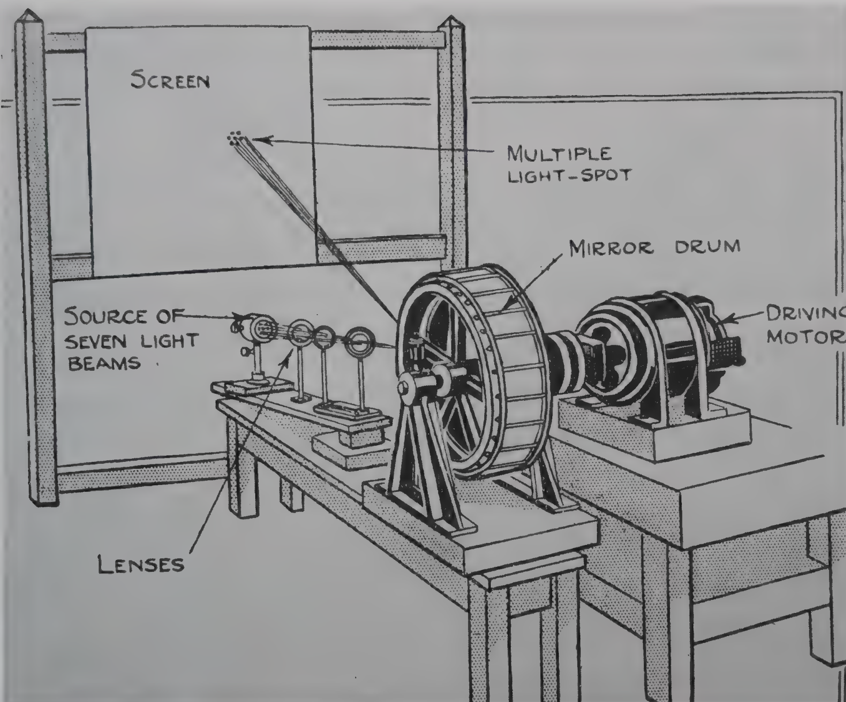


Fig. 25. Mirror wheel large screen television display. (E. T. Larner, *Practical Television*, p. 107)

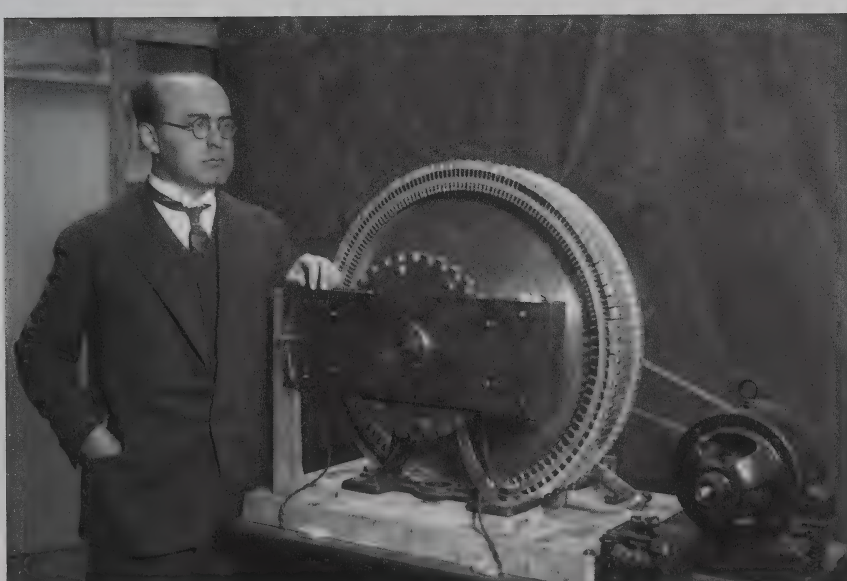


Fig. 26. August Karolus with mirror wheel. (Bundersarchiv, Bild 102-10748 Foto: o.Ang., Nov. 1930)

polarizing filter and then is directed to a vertical polarizing filter, the light is blocked. It was also known that if the angle of the horizontal filter was changed to approach vertical, light would pass through, increasing proportionally as it approaches vertical. With a Kerr cell placed between two Nichol prisms, acting as the polarizers, the light passing through could be modulated by the amount of voltage applied to the Kerr cell (Fig. 27). The complete assembly, including a high-intensity light source, was sometimes referred to as a Karolus lamp. This combined with the mirrored wheel could be used to scan a high-intensity modulated light beam both vertically and horizontally. Alexanderson took this concept, and others learned on his European trip, back to the lab in Schenectady, NY.

Much of Alexanderson's research involving the projection of a large screen television image was conducted for two purposes. First was the idea of sending the movie from Hollywood to the theatre electronically, thus avoiding the cost of shipping hundreds of movie prints around the country. The second was to offer television as an improvement over the film newsreels by using television to instantly send news stories around the country. To demonstrate the use of television for news events, there was a newsworthy event not too far away from GE research in Schenectady. On August 21, 1928, New York Governor Al Smith was going to make a speech at the state capital in Albany, to accept his party's nomination to run for president. A flying-spot scanner, using the light from a 1000 watt bulb passing through a 24-hole disc, was set up to scan the activity (Fig. 28), and the reflected spot was picked up by photocells on tripods. The electrical signal was sent the 18 miles by phone line to GE radio station WGY, located in Schenectady.[33]

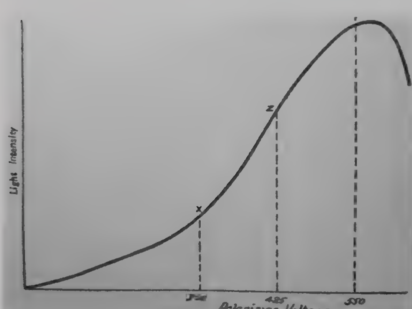


Fig. 27. Response curve of Kerr cell, light intensity vs polarizing voltage. (F. J. Camm, *New Television and Short-Wave Handbook*, p. 40)

This equipment was sensitive enough to recognize the reflected light of the flying spot while not being overloaded by the daylight on the scene. GE engineer Ray Kell operated the camera. The test rehearsals went well. When the time came, the governor was there and the speeches began, the newsreel film cameramen turned on their arc lights. This intense light washed out the flying spot and the television image. Although still claimed as a technical first, it may be assumed there weren't many viewers to complain.

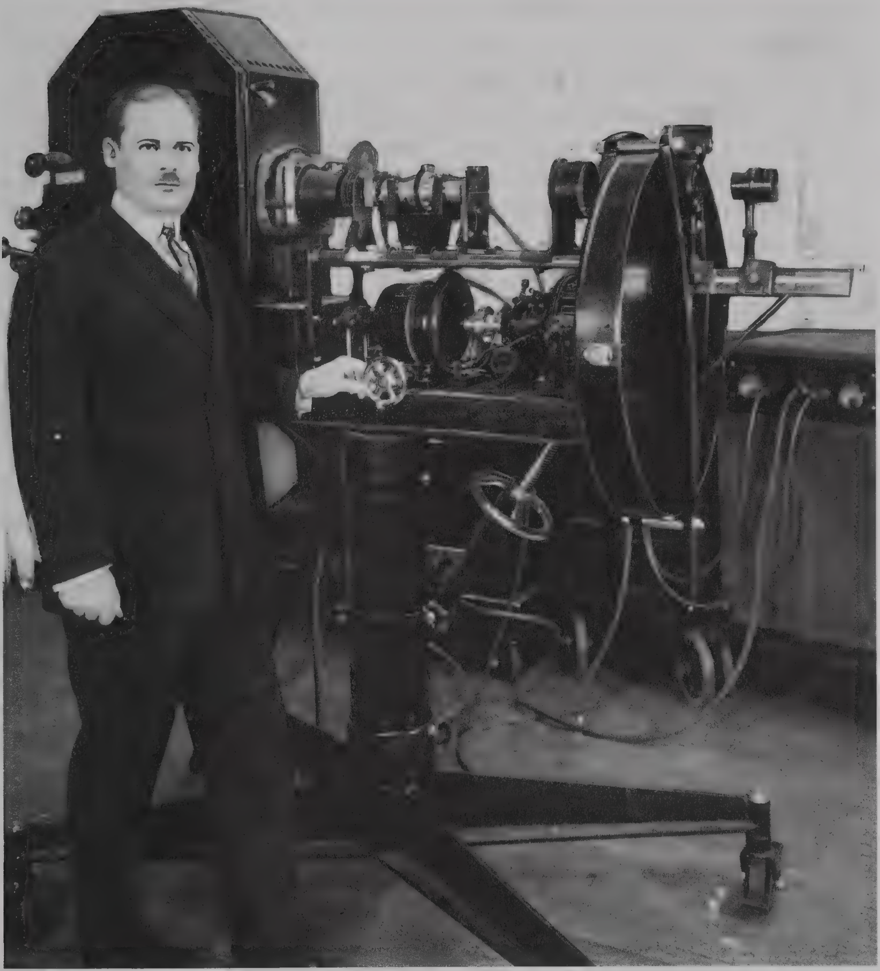


Fig. 28. Press release photo, Alexanderson with projector. (Author's collection)

The First Television Play is Broadcast

The television devices for home use resembled the other work being done with the Nipkow disc. Receivers were built and one was installed at Alexanderson's home. Noticeable in pictures of the home receiver is one innovation. Alexanderson can be seen holding a small control to sync the image, which was frequently required. Another small tabletop receiver was produced, which was known as the Octagon due to the shape of the cabinet. A flying-spot scanner was produced and cameras containing the photocell were produced.

To learn the requirements to provide acceptable television broadcasts, a production of a play titled "The Queen's Messenger" was produced (Fig. 29). This radio drama was adapted for television

because of the small and simple set, and was simple to cover with a flying spot and photocell cameras.[34] Photos of the event show the spot projector, a photocell camera, and an Octagon television receiver. The proposed home television set was used as a monitor (Fig. 30).

A number of public demonstrations were made in local theatre settings. One demonstration for executives included RCA's David Sarnoff. Sarnoff, through RCA, had been funding some of Alexanderson's work at the time. Although using the best available technology, the mirror drum, Kerr cell, Karolus lamp and Alexanderson's seven-spot projector, there was much improvement needed for television to replace film presentations. Alexanderson's work helped outline the requirements that would be needed for an acceptable broadcast television service. From this point, he seemed to step back from this work, perhaps because he realized that the only answer would be electronic television and perhaps because he saw the progress already made by RCA.


Fig. 29. First play television broadcast, "The Queen's Messenger." (*Radio News,* Dec. 1928, p. 525)


Fig. 30. General Electric Octagon scanning disc display. (Henry Ford Museum, Dearborn, MI, photo www.bretyl.com)

Westinghouse and Frank Conrad

After starting successful commercial broadcasting at KDKA, Westinghouse kept up a steady research program, which included experiments with FM and shortwave broadcasting and television. Frank Conrad and his staff worked on a transmitter for "radio movies," where a disc scanned the motion picture film and produced a signal that was sent to home receivers (Fig. 31). There were some features that should be mentioned about

Fig. 31. Frank Conrad's radio movie system. Shown is Dr. Frank Conrad, research engineer of the Westinghouse Company, standing behind his "radio-movie" transmitter. (*Radio News*, Nov. 1928, p. 416)

this system. The high-intensity light was projected through a lens to concentrate a beam of light onto a scanning disc that has a series of 60 holes in a circular pattern around the disc, not in a spiral. This configuration produced a series of vertical scanning lines that passed through a second lens, which produced a sharp point of light and scanned the film. The disc rotation and the advance of the film were mechanically coordinated so that one rotation of the disc scanned 60 lines on one frame of the film. The light passing through the film then entered a cylinder containing the photocell. The movie film was run horizontally so that the vertical scanning was scanning the horizontal film.

On August 8, 1928, Westinghouse Electric invited the press and a group of distinguished radio men to KDKA in East Pittsburgh for a demonstration of "radio movies." The images were described as good as the halftone images that appeared in newspaper photos. The receiver was described as being of a standard spiral disc unit with the exception of using a mercury vapor arc light for a brighter image. It was announced that scheduled broadcasts would begin soon using the Westinghouse shortwave station, 8XAV, in East Pittsburgh.

During this period, Vladimir Zworykin was also working at Westinghouse. His efforts were directed at electronic television for both transmitter and receiver. Zworykin and others were well aware of the advantages an all-electronic television system would enjoy. Such systems were proposed by Archibald Campbell Swinton as early as 1911, and experiments by Boris Rosing in Russia were also being conducted. Zworykin had studied under Rosing, but the cold cathode tubes with no amplifiers made the early work premature. By 1928, he had made some progress on a hot-cathode cathode ray tube (CRT) display with a 60-line resolution. This was truly the first all-electronic television receiver. It was tested by viewing a mechanically scanned movie transmission using a different method of scanning a motion picture film. During the time that each film image frame advances, it was scanned by a spot of light reflected from a vibrating mirror assembly, moving the light horizontally over the film frame. Vertical scanning was accomplished by the advancement of the film. The Zworykin work was done under Westinghouse research, not related to Conrad and KDKA. This entire system was different from the experimental movies being broadcast by Conrad. Why the two Westinghouse efforts were not coordinated is unclear.

The Mechanical TV Boom

As the 1920s progressed, so did the development of radio transmitters and receivers. Improvements were made in both components and circuit design. The progress made by the nineteenth-century inventors gave the public a hint of what was possible in television. In the late 1920s, new vacuum tubes, such as the pentode, brought higher gain, tubes with indirectly heated cathodes made AC operated sets possible, and power tubes provided higher output. Radio engineers found ways to move radio operation into

shorter wavelengths and more bandwidth was available. Twentieth-century television engineers used these developments to improve the mechanical televisions shown in the lab, and applied the improvements to receivers available factory-made for the home.

New companies and young engineers worked with a new business model to provide both the programming, broadcasting, and the receivers for those customers who wanted the latest thing for their home. Work on electronic television had been continuing slowly, primarily by Farnsworth and Zworykin, in the United States. They were still far from ready for public demonstration, so mechanical television led the way in the late 1920s into the 1930s.

The Crater Tube and the Lens Disc

The neon glow lamp, which was in common use, was unable to supply the intense point of light needed for a lens disc system. Engineers had determined that as little as 1/4000 of the light generated by a neon glow lamp passed through the tiny hole in the disc at the instant a picture element was displayed. More frames and more lines in the image only worsened the problem. The answer was a new device, referred to as a crater tube, the name derived from the shape of the elements in the tube. The point of light occurred at the hole in the center of small elements of the tube. This type of gas discharge tube concentrates the ionization of the gas at the small point of least resistance. A heater element was added around the electrodes to increase performance. This physical design also takes advantage of the fact that the ionization is more intense where the gas is confined between solid boundaries. This caused heat to build up and large crater tubes designed for larger projection screens had a water-cooled section to protect the negatively charged electrode. Experiments with mixtures of the gases in the crater tube could also produce a whiter light than the old neon glow tubes.

With a bright modulated point source of light from the crater tube, it would be possible to improve the Nipkow disc by adding a small lens to each hole in the spiral (Fig. 32), versus having a large single magnifier fixed that is used by the viewer (Fig. 33). Now the point of light could be focused to paint the light across a rear projection screen, allowing more viewers at a greater distance from the screen. These new devices, combined with improvements in the photocells converting the light at the transmitter, the new class of engineers brought the new television engineers more opportunities for overall improvement in the television art.

Fig. 32. Lens disc and crater tube. (Author's collection)

Fig. 33. Jenkins Model 100 scanning disc. (Author's collection)

Jenkins Television Corp.

The Jenkins Television Corporation was founded in 1928 and purchased the television patents from Francis Jenkins. Jenkins stayed in Washington, DC, at Jenkins Laboratories, keeping up his research and a schedule of broadcasts. Jenkins was paid $250,000 in cash and stock in the new corporation that would have been worth much more if the company was successful. The new company was structured to produce televisions for sale and set up a broadcast station to send signals across the New York City region. In 1931, Jenkins suffered a heart attack, and he was never able to fully recover. There were no new developments from the lab and Jenkins died in 1934. Of course, with no breakthroughs from the lab, the sales of televisions at that time did not have the revenue that was needed to support this startup, and the company failed in 1932. It was taken over by the De Forest Radio Company and a new name, De Forest-Jenkins Radio and Television was hung on the factory.

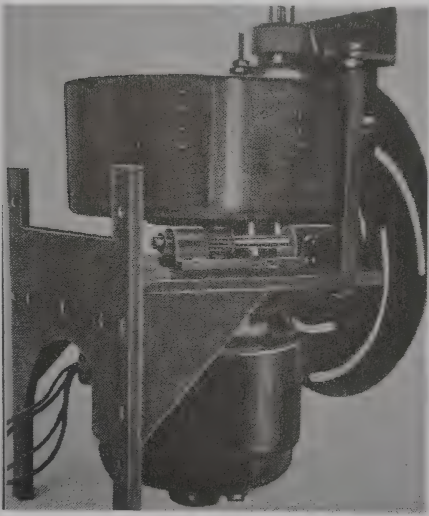
This did bring some new life and newer technology to the company. The idea of the revolving drum instead of a disc was put to use. This design enabled the production of a somewhat larger display in a more compact cabinet. The two models offered the interlaced pattern, one, Model 201 with 45 lines, triple interlaced (Fig. 34), and also a 60-line quadruple interlaced system that used a

Fig. 34. Jenkins Model 201 scanning drum and receiver. (Antique Wireless Association Museum, East Bloomfield, NY)

4-element neon lamp with rotating contact points mechanically synchronized to light the proper holes in the drum. To block light from the holes that are not part of the interlaced pattern intended for the screen, a disc with curved slots blocked all of the holes except for the intended set. The disc was synchronized by a mechanical drive from the motor spinning the drum (Fig. 35). The light passing through the disc was magnified for the viewer.

Soon, as the crater tube became available, the company switched to the lens hole disc design. The unique feature of the Model R-400 was the tilted lens disc and the mirror reflecting the light to the screen (Fig. 36). This allowed the use of a cabinet in style with the cathedral radios on the market.

Fig. 36. Jenkins Model R-400 projector radiovisor. (Antique Wireless Association Museum, East Bloomfield, NY)



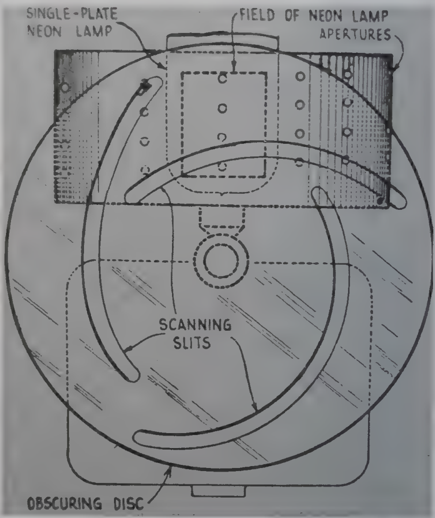


Fig. 35. Mechanism inside the Jenkins Model 201, showing the drum and scanning slit assembly of this 45-line triple laced receiver. (*Television News*, Mar–Apr 1931, pp. 60, 68)

Allen B. DuMont

Allen B. DuMont started his career with Westinghouse at the Newark works. His work as a young engineer involved improvements to radio vacuum tube production. In 1928 he left Westinghouse for a position as vice president of engineering for the De Forest Radio Corp. Soon, the Jenkins Company filed for bankruptcy and the De Forest Company purchased all of the assets. This gave DuMont the opportunity to become involved in the television business. At this time the best technology involved the scanning drum glow lamp design and later a crater tube and a lens disc design.

The business fortunes of what became De Forest Radio and Television were not much better than those of Jenkins. Within a few years, the De Forest Company became another victim of bankruptcy and DuMont was out of a job. It would appear that during this time, DuMont came to realize that the future was in electronic television. He took the knowledge gained from his early work on vacuum tubes at Westinghouse and started small, with a $500 investment and working in his basement. He initially built cathode ray tubes for use in laboratory oscillographs (oscilloscopes) and soon he was building complete lab equipment. He became known in the industry and served on committees developing television standards.

The DuMont Company's rise in television was meteoric. In several years it would include the manufacture of some of the best television receivers as well as studio and transmitter equipment and a broadcast network. Unfortunately going against much bigger corporations, the company also had a meteoric fall.

Hollis Baird, 1906–1990

Another man named Baird (no relation to John L. Baird) named Hollis S. Baird would play an important role in the history of television. He was a young newcomer to the television business and a founder of the Shortwave and Television Company in Boston, MA. Although he was a minor owner, he was the major factor in engineering the company's products. His designs included a home television receiver that utilized a rotating drum (Fig. 37) as well as kit models that were also made using a perforated belt. Hollis Baird also designed several models of shortwave receivers that had the range to bring in the experimental broadcasts.

Fig. 37. Hollis Baird scanning drum. (Author's collection)

Of course, in the days of mechanical television, the company that built the televisions had to broadcast the programs for the experimenters to view. That meant that Hollis Baird had to build a television broadcast studio and transmitter.

Although the Baird Company was underfinanced, it did manage to accomplish a lot. They were regular broadcasters (station W1XAV), built transmitters and receivers, and sold shortwave receivers. As advances were made in electronic television, Baird was one of the few that kept up with the technology. Baird was able to move into electronic television by building much of his own equipment but appears to have been unable to keep up with the cost of broadcasting and building electronic television.

Ulises Armand Sanabria, 1906–1969

Question: What do William Randolph Hearst, Eskimo Pies, and an enthusiastic teenage inventor have in common? These people and Eskimo Pies were all factors in the mechanical television boom that occurred in Chicago and the midwestern United States. The story starts with an enthusiastic teenage inventor, Ulises Armand Sanabria. Confidence is a good characteristic for a young engineer, and one that wants to be a successful inventor also needs to be able to sell himself. Sanabria started to develop these characteristics at a young age, when at 15 years of age, he told his young girlfriend that he was going to invent television. He would soon prove that he truly had these talents. At age 19 he demonstrated a working television system. This came four months after Jenkin's television demonstration, making Sanabria the third inventor to demonstrate a system. He used that success to convince none other than William Randolph Hearst to invest $50,000 in his work (Fig. 38).

Fig. 38. Hollis S. Baird and Ulises Sanabria discuss television, 1931. ("The Romance of Shortwave and Television," *Shortwave and Television*, 1931, p. 22)

Soon Sanabria had set up a laboratory in offices in the Hearst Building in Chicago and he received continued financial support. In June of 1928, he sent experimental broadcasts over station WCFL on its regular AM broadcast transmitter on 620 kHz. Equipment was also built to broadcast movies. Images were described as distinctly recognizable.[35] One of the innovations patented by Sanabria was to use interlacing to reduce flicker in the scanning disc system. This system involves scanning alternate lines instead of progressively scanning down the frame. In electronic television systems, an image frame consisted of scanning a field of odd-numbered lines then a field of even-numbered lines. The viewer would then see a frame of the two combined fields. In this way, the same resolution has twice as many flashes before the viewer's eyes, and the appearance of flicker is reduced. Sanabria designed a disc with three segments that gave a triple interlaced image so that in one rotation of a disc with 45 holes, the scan covers the first line then the next hole skips two lines and scans line 4, then line 7, and so on. The next segment scans lines 2, 5, 8, and so on, while the third segment scans lines 3, 6, 9, and so on. While the viewer sees 45 lines with each rotation, the viewer also saw the image occur top to bottom, three times during that rotation. Much of Sanabria's work involved displaying large images for presentation to a large audience (Fig. 39). He also produced equipment to get television on the air in Chicago. Broadcasting began with an affiliation with WCFL and a regular schedule was instituted.

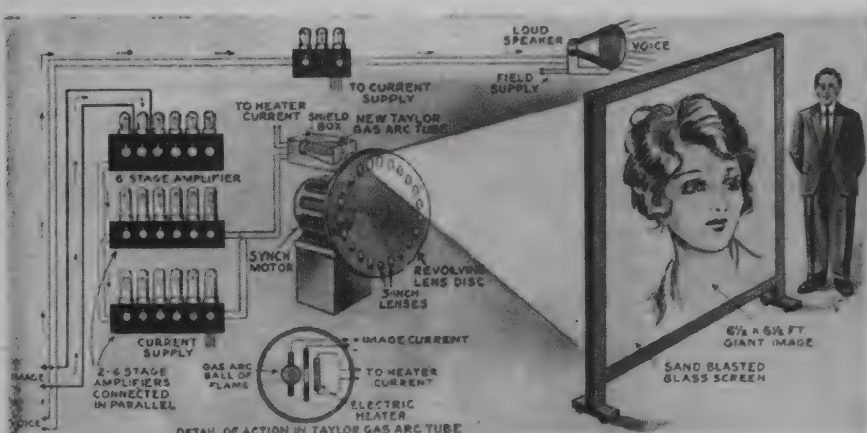


Fig. 39. Diagram of Sanabria large screen television system. The Sanabria receiver, reproducing both the image and sound picked up at the transmitter, is shown opposite; the link may be either wire or radio. After enormous amplification, the image-currents are impressed on the gas-arc tube, which throws a beam of enormous power. (*Everyday Science and Mechanics*, Nov. 1931, p. 695)

Western Television Corp.

Now the Eskimo Pie enters the story. Producing the popular ice cream treat was a very profitable business for Clem F. Wade, enough so that making a risky investment in a new technology that could have a big payoff, would seem like a good idea. He formed the Western Television Corporation, and with help from Sanabria, they started a broadcast service and produced a table model disc receiver called the Visionette (Fig. 40). The database maintained by the Early Television Foundation shows 35 surviving Visionettes, many more than any other mechanical set by any manufacturer. It can be inferred that this is the result of more of these being produced than other sets and more were produced because better programming gave people reasons to buy them.

Soon, other broadcasters in the Midwest joined in. Kansas State University in Manhattan, Kansas, and Iowa State University in Ames, Iowa, began to make regularly scheduled broadcasts. The format was compatible with the sets made by the Western Television Company, as Visionettes were being sold in those areas. An engineer working for Western told of using his receiver at home in the Chicago area, receiving the signal but having difficulty keeping it in synchronization. When the station identified itself, he learned the cause of the problem. The Chicago station did not come on the air as scheduled. He was actually receiving the Kansas City broadcast. Since these televisions were manually synchronized, and the synchronous motors spinning the disc were receiving their AC power from the same power companies, the images would stay fairly steady. When a Visionette in Chicago received the signal from Kansas City, the two power companies were not in sync and maintaining a synchronized image required constant adjustment.

Fig. 40. Western Model "Visionette" scanning disc display. (Author's collection)

As the television boom continued, the Western Television Company produced what would be called the next generation of mechanical television. They used the Sanabria triple interlaced disc system with 45 holes in three segments of 15 each (Fig. 41). Another advance was to change the viewing of the image from a system where one or maybe two people look through a magnifying glass to looking directly at the disc. Western produced two models that utilized the rear projection lens disc. The Model 41 tabletop set also included a receiver for the television signal (Fig. 42). The

Fig. 41. Western triple interlaced 45-hole lens disc. (Author's collection)

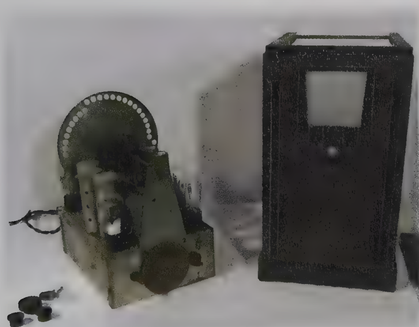


Fig. 42. Western (Echophone) Model 41 television receiver. (Author's collection)

Fig. 43. Western "Empire State" television and sound receiver. (Early Television Foundation, Hilliard, Ohio)

Empire State model included these same items as well as a second receiver for the audio portion of a broadcast (Fig. 43). Its unique art deco appearance couldn't help the quality of the images and the quality of the broadcast programming.

In this new design, the image appeared on a slightly larger translucent screen. The image is projected from the disc to the rear of the screen. To accomplish this a new type of disc, called a lens disc, was introduced. This was used in the Sanabria triple interlaced disc system shown previously in Fig. 41. Each hole in the lens disc contains a lens that is set to focus the light onto the rear of the screen. This required that the modulated light be produced by an intense point source. A new device was needed to provide this intense light.

Other Manufacturers

Along with the large companies and companies formed by inventors, there were several others producing mechanical televisions to add to their radio products or startup companies hoping to ride the TV boom. Some also produced kits of components for the home experimenter.

The Daven Company of Newark, NJ, produced signal amplifiers to drive the neon glow lamps, discs, and other components. They also had a unique product in their line, both as a part or a complete receiver. It solved the problem for the experimenter hoping to receive images from several broadcasters at a time when there were no official standards. They used a large disc that enabled viewing of three different formats.[36] The disc had an outer spiral, inner spiral, and middle spiral. With a good radio receiver attached to the Daven amplifier, the experimenter can search the airwaves for more viewing opportunities and move the neon lamp and socket up a rail for the matching format of 48 holes, 36 holes, or 24 holes (Fig. 44).

Fig. 44. Daven 1931 triple format scanning disc receiver. (Early Television Foundation, Hilliard, Ohio, website)

The Television Manufacturing Company of America, located in New York City, built scanning disc television kits and complete receivers in a cathedral-style cabinet. The most noteworthy accomplishment of the company was a public relations event. In 1931, the company president, Mr. A. Pollak rented a storefront at Broadway and 52nd St. to provide six weeks of free demonstrations of the See-All models (Fig. 45). Crowds of the curious came through day and night.[37] The company's estimate of a half-million visitors viewing high-quality images may have been an overly optimistic report, as the 1932 line of new models, announced at the demonstrations, did not appear to be realized. This company made a valuable contribution to the art of television by demonstrating their receivers to the public, but it appears that the public saw television that wasn't ready for them.

The Pilot Radio Corporation in Brooklyn, NY, had roots going back to 1919 as a manufacturer of radio parts. They soon went on to produce popular kit radios such as the Wasp series of kits and plans. As the interest in radio grew, they began to produce a number of complete models. At the same time, Hugo Gernsback in New York City was the publisher of many popular technical periodicals, including *Radio News*. He was a long-time television enthusiast and published many articles and editorials promoting television development and started another publication, *Television News*. Convinced that as more people saw television it would gain acceptance, his organization also had a broadcast

Fig. 45. See-All scanning TV. (National Capital Radio and Television Museum, Bowie, MD)

station, WRNY, located across the river in New Jersey. When Gernsback wanted to add a television broadcasting service to WRNY, he contracted to work with Pilot.[38]

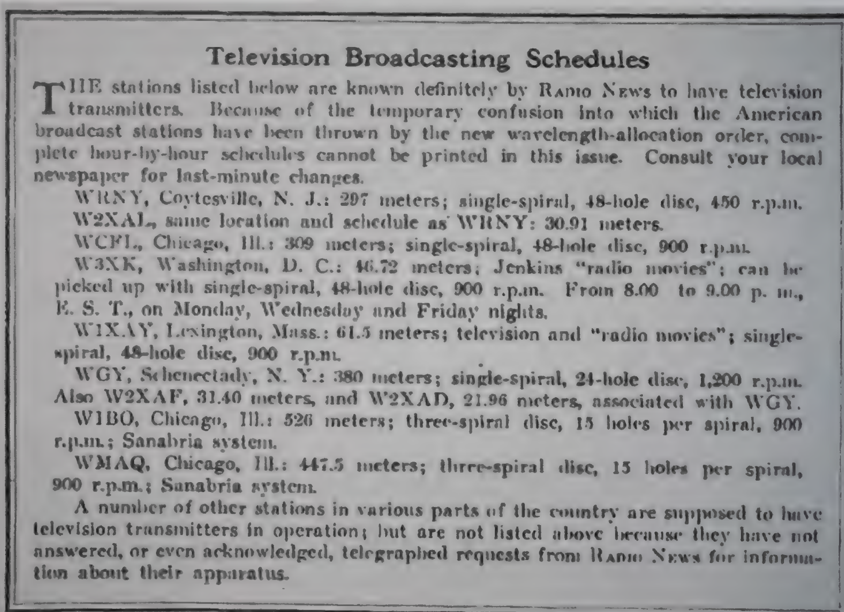
Soon after testing, it was decided that higher output from the photocells was required. Researchers at the University of Illinois were contracted to build new larger tubes. Twelve-inch diameter tubes were constructed and claimed to be the largest made to that date.[39] WRNY was broadcasting to the New York City area from a transmitter in Coytesville, NJ, and Pilot was building disc televisions with a built-in Pilot receiver (Fig. 46).[40] It is unclear how many were made as there are no known surviving sets. *Radio News* published a list of the confirmed television broadcasting stations and their formats in 1929 (Fig. 47). In 1932, lists would show over 30 mechanical television stations on the air.

On the west coast, Don Lee, an early radio broadcaster in Los Angeles, was

Fig. 46. Pilot scanning disc television under construction. (Edgar H. Felix, *Television, Its Methods and Uses*, p. 144)

also a mechanical television broadcaster. His young engineer, Harry Lubcke, who had worked for Farnsworth, had the job of building the television station. Transmission began with 80 lines at 15 frames per second, broadcast on shortwave as W6XS, in 1931. The company published plans for experimenters to build their own receivers. Although latecomers to mechanical television, the company soon became an early electronic television broadcaster.

In England, the Scophony Company developed a mechanical television display that reached the rate of 405 lines. This was made possible by an invention by J. H. Jeffree named the Jeffree cell. It was able to modulate a light source 200 times brighter than was possible with the Kerr cell that was being used by others. The display used special lenses and two mirror wheels moving at high speed. With the additional light intensity, the display could project an image of acceptable brightness at the higher line rate.



Television Broadcasting Schedules

THE stations listed below are known definitely by RADIO NEWS to have television transmitters. Because of the temporary confusion into which the American broadcast stations have been thrown by the new wavelength-allocation order, complete hour-by-hour schedules cannot be printed in this issue. Consult your local newspaper for last-minute changes.

WRNY, Coytesville, N. J.: 297 meters; single-spiral, 48-hole disc, 450 r.p.m.

W2XAL, same location and schedule as WRNY: 30.91 meters.

WCFL, Chicago, Ill.: 309 meters; single-spiral, 48-hole disc, 900 r.p.m.

W3XK, Washington, D. C.: 46.72 meters; Jenkins "radio movies"; can be picked up with single-spiral, 48-hole disc, 900 r.p.m. From 8.00 to 9.00 p. m., E. S. T., on Monday, Wednesday and Friday nights.

W1XAY, Lexington, Mass.: 61.5 meters; television and "radio movies"; single-spiral, 48-hole disc, 900 r.p.m.

WGY, Schenectady, N. Y.: 380 meters; single-spiral, 24-hole disc, 1,200 r.p.m. Also W2XAF, 31.40 meters, and W2XAD, 21.96 meters, associated with WGY.

W1BO, Chicago, Ill.: 526 meters; three-spiral disc, 15 holes per spiral, 900 r.p.m.; Sanabria system.

WMAQ, Chicago, Ill.: 447.5 meters; three-spiral disc, 15 holes per spiral, 900 r.p.m.; Sanabria system.

A number of other stations in various parts of the country are supposed to have television transmitters in operation; but are not listed above because they have not answered, or even acknowledged, telegraphed requests from RADIO NEWS for information about their apparatus.

Fig. 47. Television broadcasting schedules of 1929. (*Radio News*, Jan. 1929, p. 631)

This development, coming in 1938, had a short life as electronic television was replacing all mechanical systems.

End of the Boom

During the 1928 to 1934 television boom, a number of factors were coming into play that would change the fortunes of mechanical TV:

- The depression reduced investment capital.
- Experimental television stations were not permitted to generate revenue by advertising.
- The entertainment quality of the broadcasts was unacceptable to the public.
- Advances occurred in electronic television.
- Changes at RCA made small independent research unnecessary.

Although it would first seem that there would be no connection to the mechanical TV business, changes began to take place at RCA (Radio Corporation of America) that would change everything in the way RCA did business, including how RCA related to the rest of the radio electronics business and the development of television. From the beginning of broadcast radio, RCA marketed radio receivers built by Westinghouse Electric and Manufacturing Co. and the General Electric Corporation. How this relationship evolved is more than a chapter in radio history but it also caused a chain of events that would impact television history. During this time in the 1920s, both GE and Westinghouse did their own research in television. Also, during this time RCA was holding the patents for many of the circuits required to build competitive radios. The most important of these was the superheterodyne circuit of Edwin Howard Armstrong, and RCA declined to license this, and other patents, to the rest of the industry. This and other factors brought pressure from federal regulators to deal with what was referred to as the Radio Group (mainly RCA, GE, Westinghouse, and some others) as a monopoly.

As David Sarnoff rose to power at RCA, it was his responsibility to relieve some of the pressure from government investigators. RCA had to change the way they did business. The first of these changes involved RCA beginning their own manufacturing. To start this, RCA purchased the Victor Company in Camden, NJ, and RCA Victor was born. David Sarnoff was now in control of manufacturing radios for RCA and he began a research department in Camden. Sarnoff was very public about his views on television. He was sure it would be the next big thing and that RCA would be the leader in the field. RCA began television research in coordination with work by Alexanderson at GE and Zworykin at Westinghouse.

The government regulators still were not satisfied with the changes. Sarnoff agreed to license all of the patents in the RCA patent pool to all others in the radio business that could afford the fee. This soon brought most of the industry into the RCA fold either directly, or, for a small company, under a larger

company's license. The settlement with the government also included GE and Westinghouse divesting all of their interest in RCA. Sarnoff was able to move Zworykin and his team to RCA.

The 1930s and the depression brought hard times to the entire radio industry as well as RCA. This did not stop Sarnoff from advancing the work on television. He had the power to direct the company in this direction and he had the reputation of success and the confidence of stockholders that allowed him to make huge expenditures of Table 1 on television research.[41]

This amount in 1930 dollars dwarfed the research budget of the other organizations at the time. Also, for the same time period, research funding for research by Farnsworth was only around $1,000,000. Allen DuMont's new company could spend only $300,000 on research.[42] By comparison, these numbers overwhelmed the amounts available to the small mechanical TV companies. In reviewing the documents provided by Shortwave and Television Co. (Hollis Baird), the value of the entire company never exceeded $70,000. The De Forest-Jenkins Company could not find the buyers for their receivers and soon filed for bankruptcy. The assets were bought by RCA.

This huge effort by RCA could make a small company wonder why they should fund any television research. If a company was producing a television with a receiver under an RCA license, the results of RCA's research were available for your use.

As the 1930s came in, Sarnoff and RCA put their television research funds to good use. The decade would bring a series of field tests from the new Empire State Building and the new transmitters perched at the top. This period of research started at RCA Laboratories in Camden, NJ. It would be the most comprehensive research into creating a commercial television broadcast to date. It began by investigating something that mechanical TV inventors tried to ignore. Research began into learning what was required to create an acceptable, satisfactory commercial television system that would have the entertainment value to inspire the radio listeners to buy a television receiver for themselves.[43] Research

Table 1. Television development expenditures by RCA, 1930–1939. (Author)

Cost and expenses for patents and patent rights	$ 2,124,000
Research and advanced development	2,651,000
New York field tests, equipment, engineering and technical operation	1,494,425
Related manufacturing operations	2,170,547
Expenses related to development of TV programs	813,751
Total expenditures by RCA	$ 9,253,723

on the requirement for the system was conducted and published in the *Proceedings of the Institute of Radio Engineers.* They considered many factors:

- How many people could comfortably watch the television screen.
- How far away would they be from the screen.
- What size screen was desirable.
- How many scanning lines per inch are needed for an acceptable image.

This study gave them information to graph important factors to satisfactory television. One graph related screen size, lines per inch, and distance from the screen required to give the viewer a satisfactory experience.[44] This detailed analysis gave engineers a goal. Development would have to proceed and meet these goals or commercial electronic television would fail in the marketplace.

The research was done on a solid engineering basis. Much had to be learned in all aspects of television so that an entire industry could be created. A television camera and a receiver would not be enough. TV studios, broadcast equipment, and transmitters had to be designed. A schedule of field tests for an experimental television system was planned. The results of these tests would be analyzed and the engineers were ready to produce any advances needed. Changes could be put in place for the next test. Plans were made to increase the line rate during the test period starting at 120 lines.

The 1932 Television Field Test and a Last Chance for Mechanical Television

Although committed to electronic television, The RCA field test in 1932 was to be the last chance for mechanical TV to shine. Vladimir Zworykin's camera tube, the Iconoscope, was not ready to leave the laboratory. As would happen in show business, an understudy was given a chance to take the stage. In this case the understudy was a 120-line mechanical system that RCA had been developing. Reception would be on prototype kinescope receivers built for the field test. Transmitters were built for separate audio and video broadcasts. The tests would be in the 40–80 MHz band, assigned for experimental television, and reception tests would be measured with a radius starting at the Empire State Building.[45]

The mechanical television equipment included a 120-line spot scanner for studio work. The frame rate was 24 frames per second. As in other mechanical systems, the light from the flying spot was received by a photocell to become the video signal. A film scanner of 120 lines was built for movie broadcast. The 24 frame per second rate matched the rate used in theatrical movies. The scanning discs in both units had a provision to send a synchronizing pulse.[46] Also, a change had to be made in the scanning disc to accommodate broadcast to a receiver with a cathode ray tube (CRT). A scanning disc receiver does not need a blanking retrace line. When one hole passes the viewing area, another hole is at the starting point for the next line. In the CRT receiver, the electron beam is

cut off while the deflection circuits move it into position for the next line. This has to happen in both the horizontal and vertical movement of the beam. For this reason, additional spaces had to be added between holes in the disc to allow some dead time for the CRT to perform horizontal retrace. Another space was added between the last hole in the spiral and the first hole in the spiral, for the vertical retrace.[47]

The television receivers built by Zworykin were an advance on the receivers built when he was at Westinghouse in East Pittsburgh. Now at 120 lines with a 9-inch cathode ray tube, it had electromagnetic deflection and was built into a radio-style cabinet (Fig. 48). Due to the length of the CRT, the glass tube was mounted vertically with a mirror attached to the lid, angled to project the image to viewers comfortably seated.[48] The image quality was greatly improved over a 60-line scanning disc image. In addition to the improved line rate, the phosphor screen also reduces the appearance of the scanning lines. The TV model Felix the Cat is starting to look better (Fig. 49)!

Fig. 48. RCA prototype CRT television receiver used in a field test, 1932. (Darryl Hock collection)

Fig. 49. TV model Felix the Cat in 60 and 120 lines. (Irving Settel and William Laas, *A Pictorial History of Television*, pp. 40, 41)

The End of Mechanical TV

When Jenkins broadcast his "radio movies," he asked viewers to mail in a confirmation report. We could assume the dedicated experimenters were happy to respond. In his book, Jenkins listed all of the loyal fans on one page. There were only 30 names. Surely the true believers would keep watching and perhaps buy or build better equipment, but they could never support mechanical television as a commercial business. Ultimately having some entertainment value to capture the interest of the average radio fan was necessary.

In an interview, RCA engineer Ted Smith, who was responsible for the construction of the RCA mechanical TV station W2XBS, told this story of a TV demonstration. Their equipment was set up in a Manhattan theatre. The VIP in attendance was David Sarnoff. The demonstration played on a large screen set up on the stage. It was a successful demonstration of the highest viewing quality they could achieve at that date. Smith watched Mr. Sarnoff and party view the presentation. When they left, Smith reports that they dismantled the equipment, took it outside the theatre, and placed it in the trash. It had been obvious to all that this technology would never meet the standard of an acceptable television service.[49]

In 1927, Ernst Alexanderson wrote an article in the February 1927 issue of *Radio News*. In the article, it appears at this stage of his research, he has come to understand what would be required for a quality television system. He points out that he has had success sending quality still images, but for a 16 frame per second moving image of the same quality, he would have to send that image in 1/1000 of the time of sending the still image. He doubted that the devices he had to work with could ever do that job. He then rationalized that if a person only wants to see the moving image of a friend that he can see and recognize, then mechanical TV is capable of that job. He estimated that the mathematics of the requirements for real television are predicting a need for very large bandwidth, unheard of at that time.[50]

In 1932, Philo Farnsworth took his electronic television equipment to England for a demonstration prepared for the Baird Corporation. Farnsworth's wife attended the demonstration and she gave this remembrance, "As he came through the door, Mr. Baird caught sight of the picture on the monitor [of Farnsworth's system] and became silent. He stood there for a time. Then, breaking the spell with a visible effort, he turned without a word and left. With great empathy Phil watched him go, aware Mr. Baird had seen the death knell of his beloved spinning disc."[51]

In the 1933 interview, Paul Nipkow was asked about the progress on mechanical televisions using his discs. Although he recognized some improvements, he said more, "If I am not mistaken, however, the Braun tube, the long glass tube with the deflected cathode ray, has the most prospect for practical realization."[52] The inventor of the scanning disc was not mistaken.

However, the electronic commercial television system that was introduced at

the 1939 World's Fair did not mark the end of a motor being used in a television receiver. In 1950, color television receivers were built that incorporated a monochrome CRT mounted behind a spinning disc of red, green and blue color filters. Once again, the eye's persistence of vision would produce a realistic color picture.

Decades later, a small television camera with a spinning color filter brought us the first color television from the Apollo 12 astronauts on the moon. In the 1990s, when plasma TVs were too expensive and before flat LCD TVs became affordable, many DLP TVs were produced. These TVs, using Digital Light Processing chips, filtered intense white light through an assembly with a small spinning color wheel and the digital chip before sending the image to a rear projection screen.

It doesn't seem likely that we will need motors in our televisions in the future. As the technology of computers, software, the internet, and video displays continue to advance, it becomes more of a challenge to describe the device we are watching as a "television." However, it is important to understand "how we got to here" and the decade of mechanical television systems and the men who built them is an important part of that story.

Endnotes

1. Announcement by BBC (British Broadcasting Corp), Jan. 5, 2016.
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3. Gleason L. Archer, *Big Business and Radio,* (The American Historical Company, Inc., New York, NY, 1939) p. 431.
4. Ibid.
5. Ibid., pp. 431, 432.
6. T. Thorne Baker, p. 72.
7. Raymond F. Yates, *New Television–The Magic Screen,* (Didier Publishers, Madison Ave., New York, NY, 1948) p. 22.
8. Wilhelm Schrage, "Nipkow Lives," (*Radio Review and Television News,* Vol. II, #6, Popular Book Corp. Jan–Feb, 1933) p. 290.
9. Ibid.
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The Antique Wireless Association not only publishes this collection of articles, but also runs the AWA Museum in East Bloomfield, NY. The Museum, along with the AWA Library, is not only a great resource for historians, but also actively brings this history to the next generations through their educational programs. See: www.antiquewireless.org.

The website www.worldradiohistory.com has become an immense and indispensable archive of information on radio and television history with a collection of scarce periodicals and books instantly available.

About the Author

Author **Mike Molnar** has been an engineer working on nuclear medicine equipment for 44 years; the last 39 with his own company. Mike has also been collecting and studying antique radio, TV, and other electronic items for over 50 years. Mike has promised his understanding wife, Pam, that the time has come to start cutting back on his work responsibilities in order to do more of the things they enjoy. Mike's wife does not believe him. Simply to prove her wrong, he plans to spend more time with his assistant, Lila, hunting for more electronic fossils.

Author Mike Molar (right) and his assistant, Lila, stepped from this picture into an analog abyss. They found themselves in a 45-line triple interlaced quagmire, finally escaping from the magnifier of a Western Television Corp. "Visionette."

A Short History of Canadian Television and Technology

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The primary purpose of this research is to document some early history of how television evolved in Canada and also some advancements in television technology over the decades. In this story, the term "early television" references either the first mechanical televisions or the growth of television after WWII, depending on the context. Some of what is written here was actually experienced by the author over the decades.

The Short History

The invention of the television was the work of many people in the 19th century and early 20th century. Television stations were operational in the United States before any Canadian stations went on the air. The first experimental station with no regular programming began on January 13, 1928. General Electric programs were transmitted from station W2XB in Schenectady, New York, using a 24-line mechanical scanning system.[1] It would be safe to assume that any television station from this era would have been using a mechanical scanning system, since standards had not yet evolved.

In Canada, the first television station, VE9EC, was an experimental one based in Montreal, Quebec.[2] It broadcast between October 9, 1931, and 1935, showing neon red and black pictures. The station was owned by La Presse and radio station CKAC. VE9EC used a mechanical scanning system that broadcast 60 to 150 lines on a frequency of 41 MHz.[3] Broadcasts were witnessed by over 100,000 people who lined up to view images at the Ogilvy Department Store on Ste. Catherine Street in Montreal. Ogilvy's of the present day is shown in Fig. 1. Over time, new electronic scanning systems were able to deliver more scan lines (i.e., 441 lines) thus improving resolution tremendously.[4]

The 1940s and 1950s were a critical period for television development with the adoption of the first broadcasting standard. The 525-line National

Fig. 1. Ogilvy's department store of today. (Wikipedia By Jeangagnon - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=36663809)

Television System Committee (NTSC) standard was developed in 1941, but it had no provision for color nor would it begin volume production until after WWII ended.[5] In 1953, a second NTSC standard was adopted, which defined a new standard for color television broadcasting and was also compatible with the existing population of black-and-white receivers. NTSC was the first widely adopted broadcast system and remained dominant until 1997, when it started to be replaced with different digital standards such as the Advanced Television Systems Committee (ATSC) and others.

By the late 1940s, Canadians who lived in close proximity to U.S. border cities could watch American shows and programming where available. In order to promote the sale of TV receivers, the transmitters and the programming had to be there first. Merchants who sold televisions in Canada had to import them from the United States since there was no TV manufacturing in Canada around this time.

The first television manufactured by a major company in Canada was in 1948. However, there is debate if this was by Canadian Westinghouse in Hamilton, Ontario,[6] or by Canadian General Electric.[7]

In a September 1949 issue of *Billboard*, it was announced that Canadian Fairbanks Morse and Canadian Marconi would start to build radios and TVs for Emerson Electric for sale in the Canadian marketplace.[8] It was to be on a royalty basis as evidenced in a separate announcement. This was also the beginning of TV manufacturing for Canadian Marconi. The company also built the TV Model 100, shown in Fig. 2, which bears an identical appearance to the American General Electric Model 10T5 of 1949, shown in Fig. 3.

Another early Canadian television set was the Viking Console, shown in Fig. 4, which made its debut in 1952. The stylish set was sold by the Eaton's department store chain and manufactured by Electrohome in Kitchener, Ontario, as a private label TV. Viking was Eaton's house brand.[9] There was also the Rogers-Majestic brand of television produced by Phillips Electronics Canada. RCA opened a television production plant in Prescott, Ontario, in 1953.

Many other companies, too numerous to mention here, also got into TV manufacturing.

Television set production and acceptance was a great boom to the Canadian television industry. In 1951, there were

Fig. 2. Canadian Marconi TV Model 100. (Author's collection)

Fig. 3. American General Electric TV Model 10T5. (eBay)

Fig. 4. Viking Console TV. The set's production signaled the arrival of television in the average Canadian home. (https://www.historymuseum.ca/cmc/exhibitions/hist/tv/tv01eng.html)

more than 90,000 sets in Canada, and by 1953 this increased to over 300,000.

On September 8, 1952, the Canadian Broadcasting Corporation (CBC) made its historic television debut in Montreal as station CBFT.[10] However, Canadians with TVs had already been tuning into American border TV stations since the late 1940s. The CBC had set a target of September 1951 for the Canadian debut of television, but equipment shortages caused by the Korean War pushed the date back to 1952. Canadian Marconi designed and manufactured their own TV designs in 1951.[11]

By late 1965, the Canadian Marconi Company (CMC) decided to discontinue manufacturing home radios and televisions sets. This decision was announced in the *Vancouver Sun* on December 29, 1965.[12] CMC stated that it would discontinue manufacturing these consumer products by the end of January 1966, although it would be mid-1966 before the company was completely out of the consumer market. It also stated that an organization would remain in place for an unspecified period to honor all warranties and supply a full backup of parts. The records of the company stated that the consumer division was shut down because of increased competition,[13] which was primarily from Japan. To replace this business, the company planned to focus on divisions that specialized in higher-margin electronic products, such as commercial marine and land communication equipment, defense communications equipment, and aviation electronics.

Canadian Marconi had been broadcasting television programs using the

letters CFCF-TV since January 20, 1961, shortly after it received its first license for a private television station in 1960. The Canadian government had refused numerous applications from CMC for a television license during the 22 years from the company's first application submitted in 1938, to 1960, when a license was finally granted. Marconi's station CFCF-TV continued broadcasting regular programs until 1972, when Canadian Marconi was required to sell its broadcasting assets because of a change in the requirements that would reduce foreign ownership of these assets. CMC had received licenses for broadcast stations CFCF-AM, CFCF-FM, CFCF-CX short wave, and CFCF-TV before 1968, when *The Broadcasting Act of 1968* was passed by the Canadian Parliament. This act established a policy that the Canadian broadcasting system must be owned and controlled by Canadians.[14] It directed the Canadian Radio-television and Telecommunications Commission (CRTC) to implement this policy.

Unfortunately, the English Electric Company, Ltd., of London had purchased controlling interest in the Canadian Marconi Company circa August 5, 1953, long before this act was passed.[15] As a result of this legislation, Marconi began to look for potential buyers in 1970. Marconi had been ordered to sell its broadcasting assets by June 30, 1972, to meet federal requirements that restricted foreign companies from owning more than a 20% interest in Canadian broadcasting outlets.[16] There were five entities that bid on the broadcasting rights, and Multiple Access, a national computer service company based in Toronto, was the winning bidder. Thus ended Canadian Marconi's broadcast activities in Canada, although broadcast stations under the CFCF letters continue there to this day.

Advancements in Technology Over the Decades

Television design and technology changed immensely over the decades. These changes can be categorized into the groups shown below. These are arranged alphabetically.

Antennas

Many TVs in urban areas used rabbit ear antennas to receive signals for the reception of local TV stations. These rabbit ears consisted of two telescoping arms arranged as a V. For optimum reception, the arms were lengthened for the low VHF channels (2–6) and shortened for the high VHF channels (7–13). Sometimes the rabbit ears would have to be rotated for maximum signal reception. Ghosting was also a problem in those days. First, the primary signal from the transmitter would be received. If any of the signal was reflected from, say, a tall building or even an aircraft in flight, the reflected signal would arrive a moment later and had the effect of casting ghosts on whatever was being received. Some folks even made their own indoor antennas using tinfoil.

As the distance from the transmitter to the receiver increased, rabbit ears could no longer do the job. Cable TV had not yet arrived. Homeowners had no choice but to erect outdoor antennas.

These were affixed to a tubular mast and supported with guy wires attached to the base of the roof. The outdoor antenna could assume several configurations. In Hamilton, Ontario, two antennas were required to receive Canadian and U.S. programming. One antenna would consist of a low VHF Yagi, as typically shown in Fig. 5, which was pointed to Buffalo, NY, in order to receive channel 2 (NBC), channel 4 (CBS), and channel 7 (ABC). A VHF folded dipole with a reflector element was pointed towards Toronto to receive channel 6 (CBC) and channel 9 (CTV). Both antennas were connected to the TV set with 300 ohm twin lead and terminated on a ceramic, double pole, double throw knife switch which was affixed to the back of the TV. The two poles of the switch were connected to the antenna terminals of the TV. This arrangement meant that the viewer had to change the position of the switch depending on whether a low or high VHF channel was to be received, or to use an antenna pointed at the TV station. Since channel 7 was in the high band, and channel 6 was in the low band, it was a compromise of antenna resonance and direction. This was the typical antenna configuration for Hamilton and surrounding vicinity.

For viewers who did not want to fuss with flipping a knife switch when changing from low to high VHF channels, an all-purpose VHF/UHF antenna could be erected on a rotor. This had one slight disadvantage. If the desired station was a large azimuth angle away from the current position, the viewer would dial in the new position on the rotor

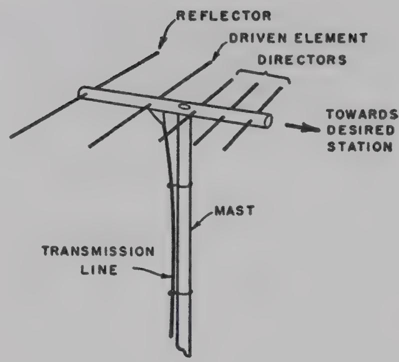

Fig. 5. Low band VHF Yagi antenna for channels 2–6. The gain of a Yagi antenna was needed to reduce snow in the picture if the TV was a long distance from the transmitter antenna. It also aided in reducing ghosts. (Public domain)

control box, then wait for the very slow rotor to swing the antenna to the new position. The rotor only moved about one rotation per minute! At installation time, the rotor control would have to be "calibrated" by first receiving all stations within the antenna's range, then marking the face of the rotor control box with the station numbers. Rotors could also be prone to icing during winter conditions. Back in the 1950s and 1960s, it was very easy to tell which houses had a TV and which ones didn't.

In September 1952, small-scale cable TV was being evaluated in Toronto and Montreal. Eventually, these early tests would create a whole new industry. As cable subscriptions grew, rooftop antennas started disappearing one by one. There is now a multitude of ways to receive television content, with fiber cable and satellite reception dominating the landscape. A segment of the population has opted to "cut the cable" and receive

their programming via high-definition, combination antennas, supplemented by the internet's streaming content sources such as Netflix or CNBC. There is still a viable market for satellite dishes in rural areas where the stations are out of range and the dwellings are spaced too far apart for the affordable installation and operation of cable TV.

Cabinets

Early television cabinets could be very ornate and were available in many types. Walnut and mahogany were two popular kinds of woods used in the fabrication of cabinets. Some sets could be purchased in a particular furniture style such as French Provincial. Some TVs came with a built-in radio and phonograph. But what was one to do if the television wore out before the radio and the phonograph?

As more televisions were sold in the 1950s, the most notable change was cabinet styling and the increase of the picture tube size to 21 inches, as evidenced in Canadian Marconi Models 168K23 and 169K23, shown in Fig. 6. For the technical person, perhaps the man of the house, hand wiring, tube count, servicing ease, and sound and picture quality were emphasized.

Cabinet styles could be as simple as a cube-shaped box sitting on peg legs or elaborate floor consoles. Black plastic soon displaced wood as the cabinet material of choice.

Cathode Ray Tubes

Cathode ray tube (CRT) sizes grew from 5 inches in the late 1940s to 43 inches in the 1990s. As the CRT size grew, it became imperative to protect the CRT

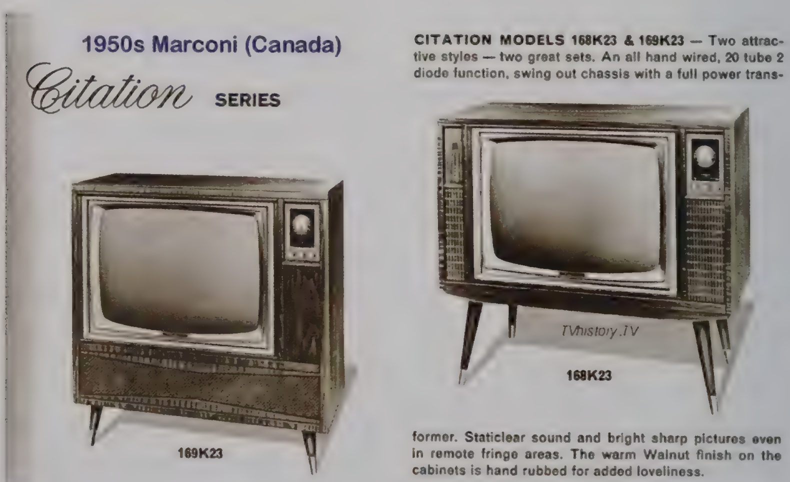

Fig. 6. Canadian Marconi 1950s Citation series TVs. The Citation Models 168K23 and 169K23 were two attractive styles and two great sets. The sets were hand-wired with 20 tubes and 2 diodes, and featured a swing-out chassis with a full power transformer. Staticlear sound and bright sharp pictures were possible even in remote areas. The warm walnut finish on the cabinets was hand rubbed for added loveliness. (Author)

from inadvertent damage by the user. To prevent an accidental implosion of the CRT, a tinted safety glass, akin to that of an automotive windshield, was placed in front of the CRT. Later on, the safety glass became an integral part of the CRT, thus eliminating the need for the occasional cleaning of the stand-alone safety glass. This also helped to reduce the cost of the television. It was this author's personal experience to have witnessed the sudden crazing of the entire safety glass on the family's television. When it happened, it sounded like a gunshot. This may have been caused by the cabinet applying stresses on the safety glass but it was nice to know that it stayed in one piece. CRTs frequently became gassy and had to be replaced. Depending on usage, one could get at least 10 years of life from the CRT. Eventually, CRT makers made the tubes last even longer; a typical 1999 36-inch RCA lasted 20 years.

During the era of CRT televisions, there were numerous shops across the country which would rejuvenate worn out CRTs. These shops became fewer and fewer and all closed their doors once LCD flat-screen TVs became the norm. CRTs could also be rebuilt, but these shops also closed their doors and the rebuilding machines were discarded.

Near the end of the CRT era, Sony offered flat-screen CRTs in their Vega series of televisions, but this was too little too late. Just around the corner was the debut of the high resolution flat-screen TV which made the CRT and projection televisions obsolete. Flat screens can display 720 lines (standard definition) or 1080 lines (high definition) and the largest models can be fabricated to be up to 108 inches diagonally. For a while, 3D television looked promising but it was discontinued in 2017 due to low consumer demand. The 4K standard (a.k.a. Ultra-High Definition) is capable of displaying 2,160 lines in progressive scanning mode. When the transition from CRT to flat screen occurred, the aspect ratio also changed from 4:3 for a CRT to 16:9 for flat-screen TVs.

In 2019, the 8K QLED standard made its appearance. (Q means Quantum.) Not much will be televised in 8K initially and the viewer will need a 50 Mbps internet link to stream it in all its glory. While human eyes are not rated in pixels, an approximation of what we can see is 40 megapixels, where 8K is 33 megapixels resolution. But our eyes don't see everything in equal resolution. The high resolution is only a small circle in the middle of our vision, which would be about 7 megapixels. So while high resolution would allow us to get bigger TV sets, it would make lower resolutions look smoother. Anything above 8K is effectively better than our eyes can see. For this type of TV, the 8K standard will make the most sense for screen sizes of 65 inches and up.

Circuit Design and Vacuum Tubes

Early televisions used an intermediate frequency (IF) of 21.25 MHz for audio and 25.75 MHz for video. This design was problematic if the viewer lived in the vicinity of an amateur radio station that operated in the 15 meter band (21.000 to 21.450 MHz). The fundamental signal could interact with the television's

IF stages and could cause interference even though the amateur was operating legally. Alternately, third order harmonics from 7 MHz transmissions could cause television interference for the same reason. If the problem could not be rectified technically, it was usually best for the operator to cease operations so as to maintain a good relationship with the neighbor. The extent of interference to television IF is not known, but it is believed to be the exception rather than the rule. Later on, this ceased to be a problem when televisions were designed with a 41.25 MHz IF for the sound and 45.75 MHz IF for the video.

In an effort to reduce cost, transformerless TV designs found their way into the marketplace. This had the effect of launching new families of standard vacuum tubes whose filaments ran on what some might call "odd voltages." Types 2FH5, 4AU6, and 10DR7 are just three examples of tubes that could be found in the series filament string in a transformerless TV. In a transformerless radio with five tubes, it's very easy to find a tube with an open filament. It must have been very challenging when a service technician was confronted with a transformerless TV having perhaps 20 tubes whose filaments were wired in series.

Nuvistor tubes, designed by RCA in 1959, were widely used throughout the 1960s in television sets beginning with RCA's "New Vista" line of color sets in 1961.[17] Nuvistors were very small metal tubes, usually triodes, that offered a low noise figure at ultra-high frequencies. A typical nuvistor is shown in Fig. 7.

In 1960 the General Electric Company combined multiple common tube types into "fat" tubes—as many as four in a single glass envelope, all heated by a common filament. The idea was to reduce the amount of power required to heat the tubes and the space they required on the chassis, as well as the costs of multiple sockets. In truth, they were designed almost completely for the color TV market. This was the apex of TV design using vacuum tubes.

Fig. 7. Nuvistor. These were miniature metal tubes that had usage for the receiving front end stages. RCA announced the first Nuvistor triode tube, the 7586, in 1959. It was intended to be a competitor to the transistor. Height: 0.8 inches, diameter: 0.435 inches. (Bob Katz, https://wtfamps.com/2018/05/16/the-nuvistor-and-bob-katz-audio-blender-via-inner-fidelity/)

By the 1970s, hybrid designs started appearing. The receiver portion of the television would be composed of solid-state circuits while the vertical and horizontal circuitry still retained vacuum tubes. As semiconductors improved, televisions became totally solid-state except for the CRT. Controls started to disappear, replaced with pushbuttons and on-screen menus.

When TVs were 100% vacuum tube, it took nearly 30 seconds for the tube filaments to come up to operating temperature after the set was powered up. In fact, this was the norm for all vacuum tube equipment. When TVs first went solid-state, the only tube left with a filament was, of course, the picture tube. To reduce the warm-up time of the CRT filament, manufacturers designed a “standby” mode whereby a reduced filament voltage was applied to the CRT when the set was powered off. This reduced the warm-up time to less than 10 seconds, and increased the CRT life by reducing thermal transients.

Color Broadcasting

Probably the biggest innovation in TV technology was the introduction of color broadcasting in the early 1950s. The initial proposal by CBS for a color TV standard was incompatible with the existing base of black-and-white TVs; regardless, the FCC approved this standard in 1950. A short while later, a compatible standard was developed by RCA whereby the black-and-white sets simply ignored the luminance and chrominance information found in the color signal, and the FCC changed their approval to the compatible system in 1953.

Color TV was introduced in Canada on September 1, 1966. Canada was the third country in the world to get color TV, after the United States in 1953 and Japan in the early 1960s. High prices for color televisions and the scarcity of color programming greatly slowed its acceptance in the marketplace. It was not until the mid-1960s that color sets started selling in large numbers in the United States, due in part to the color transition of 1965 in which the major networks announced that over half of all network prime time programming would be broadcast in color that autumn. The first all-color prime time season came just one year later.

On August 31, 2011, Canadian local over-the-air television stations in certain areas stopped broadcasting in analog and started broadcasting digital signals.[18] (The United States had previously converted on June 12, 2009.) The switch to digital affected television viewers who receive local, over-the-air TV stations using an outdoor antenna or “rabbit ears.” These viewers needed either a digital converter box, such as shown in Fig. 8, or a television with a digital tuner. In the alternative, they could receive their TV services from a cable, satellite, or other service providers. If they decided to purchase a digital converter box, they could purchase one with the analog pass-through feature. This feature enabled the viewing of both digital and analog signals which may be important for viewers that receive both types of signals.

Fig. 8. Digital TV converter box. This was a short-lived product as TVs were quickly bought new with only the digital tuners. (By Jeffrey Beall - own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=4973347)

Controls

Most early monochrome (black-and-white) TV sets had the following controls: volume, channel selector, fine tuning, brightness, contrast, horizontal hold, and vertical hold. These were all accessible to the viewer.

It was not uncommon to frequently readjust the horizontal or vertical hold controls to either keep the picture from breaking up or rolling respectively. The vertical hold control was usually nested with the set's front or side panel controls while the horizontal hold might be at the back of the set. When channels were changed, it might require that the fine tuning control be adjusted. As better circuitry were included in TV designs, the fine tuning, vertical hold, and horizontal hold controls became obsolete.

Costs

In the era of vacuum tubes, all equipment had to be handcrafted. Robotic assembly of circuit boards had yet to be invented. As a result, televisions were very expensive in the 1950s and 1960s when compared with the average factory wage of the era. For example, a 21-inch Simpson Sears Silvertone television cost C$295 in 1955. To a factory worker making a wage of a dollar an hour, it took 295 hours of labor to pay for the set. Had manufacturing techniques and technology not changed, that very same TV would cost C$2,728 in 2017 when inflation was factored in. Compare that to today's TV cost versus wages and it can be seen that it only takes 20 to 40 hours of labor to pay for a medium-sized flat-screen TV in 2017. These prices continue to come down as large-scale integration became common.

Until the arrival of flat-screen TVs, several significant developments helped to drive down manufacturing costs. First came the introduction of printed circuit boards. Tube sockets could be soldered directly to the board, thus eliminating the need to wire filament strings. The introduction of Compactron and Novar tubes reduced the tube count. Solid-state was probably the biggest factor in driving down cost, as well as the use of plastic cabinets to replace wood.

Programming

In the beginning, television broadcasts were not 24/7 because there was not enough programming and viewership to fill the available time. Most stations signed off at midnight and didn't resume operations until morning. Stations usually broadcast the "Indian-head" test pattern of Fig. 9 so that technicians could make transmitter adjustments. After checks were completed, the station would stop transmitting until the usual 6 a.m. start of programming.

The Indian-head test pattern is a black-and-white television test pattern that was introduced in 1939 by RCA of Harrison, New Jersey.[19] It was also used in Canada following the Canadian national anthem sign-off in the late evening.

During the late 1950s, the test pattern was seen less frequently, because there were fewer sign-offs, on fewer stations, and for shorter periods in the morning, since new and improved TV broadcast equipment required less adjusting. In later years, the test pattern was transmitted for as little as a minute after studio sign-off while the transmitter engineer logged required FCC/Industry Canada transmitter readings, and then turned off the power. Towards the end of the Indian-head TV era, around the late 1970s, there was no nightly test pattern on some stations, when automatic logging and remote

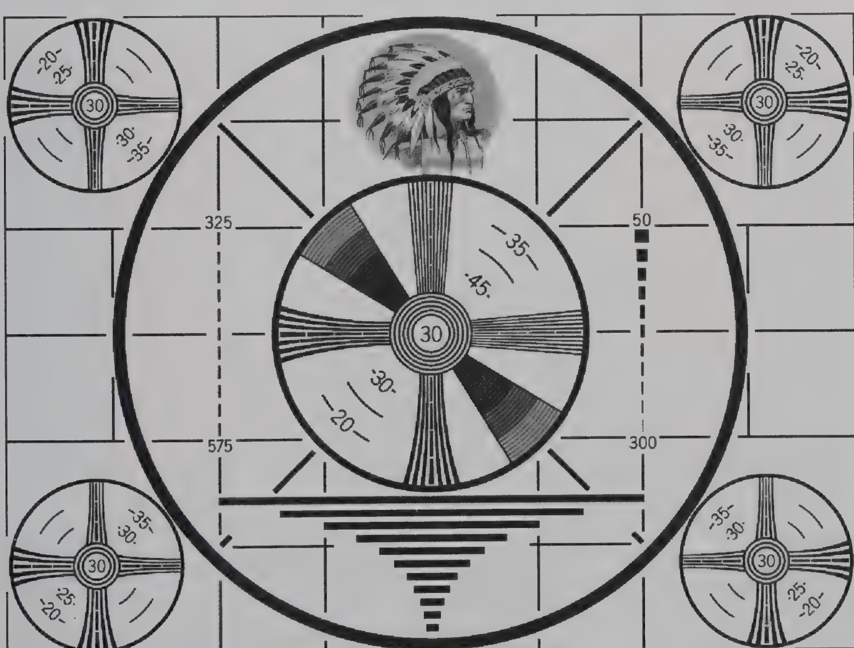

Fig. 9. This is the Indian-head test pattern transmitted by a station when regular programming was finished for the day. This enabled the station engineer to perform any required adjustments to the transmitter. (Public domain)

transmitter controls allowed shutdown of power immediately after the formal sign-off.

After an immediate transmitter power off, in lieu of the Indian-head test pattern and its sine wave tone, a TV viewer heard a loud audio hiss and saw "snow" on the TV screen. When U.S. broadcasters transitioned to color television, the SMPTE color bars of Fig. 10 superseded the black-and-white Indian-head test pattern image.

In general, the programming of the 1950s and 60s could be slotted into three groups. News and game shows were featured in the morning; soap operas in the afternoon, and primetime programs in the evening hours between 8 and 11 p.m. Westerns, police dramas, and variety shows made for popular viewing during prime time.

Program listings were published in *TV Guide,* whose first issue was released on April 3, 1953, in the United States.[20] Prior to that time, listings were published in local viewing areas. As an example, Lee Wagner (1910–1993), who was the circulation director of Macfadden Publications in New York City, printed a New York City area listings magazine in 1948 called *The TeleVision Guide*. In Canada, *TV Guide* originated as a domestic version of the American *TV Guide* before being spun off into a separate print publication that was published from 1977 to 2006, at which point it ceased publishing and its content was migrated to a website.

Fig. 10. The SMPTE test pattern replaced the Indian-head pattern as color television took over from black-and-white. (Public domain)

The first Canadian stations came on the air in September 1952. These were CBFT in Montreal and CBLT in Toronto. In Canada, television developed differently than in the United States. There were two major reasons for this. First and foremost was the fact that Canada has two national languages, namely English and French. It was therefore necessary to develop both French and English broadcasting networks and programming to service the French-Canadian marketplace which was mainly situated in the Province of Quebec. The second reason was the influence of American programming. It was much easier to obtain the rights to air American shows rather than develop programming of Canadian content.

Many early television programs were live because a cost-effective video recorder had not yet been developed. The first commercial video recorder, the Ampex VRX-1000 shown in Fig. 11, did not make its debut until 1956. Because of its $50,000 price at the time, the recorder could only be afforded by the television networks and the largest individual stations.[21]

Whatever happened to channel 1? During the era of experimental TV, channel 1 was assigned to 44–50 MHz, which was located at the lower end of the VHF band. In 1940, the FCC reassigned 42–50 MHz to the FM broadcast band, and Channel 1 was reassigned to 50–56 MHz. In the spring of 1946, after FM was moved to 88–108 MHz, Channel 1 was reassigned to 44–50 MHz. Channel 1 was abandoned on June 14, 1948.[22] The vacancy was reallocated to fixed and mobile services. More on this can be found in the story titled "History of FM Radio: 1940s to 1960s" in *AWA Review* Volume 34, 2021.[23]

Scanning Systems

In the United States, mechanical scanning methods were used in the earliest television systems in the 1920s and 1930s. They broadcast in the 2–3 MHz band until the FCC created allotments in the 40 MHz band. The vacated spectrum was then reassigned as the police band. One mechanical TV system used 48-line images. Next came 60-line images. All mechanical television was considered to be "experimental." It should be pointed out that the entertainment value of mechanical transmissions was non-existent, and broadcasts were rare and limited in length. By 1935, low definition electromechanical television broadcasting had ceased in the United

Fig. 11. Ampex VRX-1000 videotape recorder. This was very expensive and could only be afforded by the television networks and the largest individual stations. (Wikipedia photo by Karl Baron from Lund, Sweden)

States except for a handful of stations run by public universities that continued operating up to 1939. The Federal Communications Commission (FCC) saw television as being in a continual flux of development with no consistent technical standards, hence all such stations in the United States were granted only experimental and non-commercial licenses. This hampered television's economic development. Obsolescence was "easy" to handle in those days because TV set sales to the public did not begin (in earnest) until the post-war period. The various experimental standards affected only a small number of laboratory sets and a small number of "field" test sets (perhaps in the low hundreds). In Canada, it would have been a similar situation for the elite few who could even afford to buy a set to receive experimental American broadcasts.

All-electronic scanning television, first demonstrated in September 1927 in San Francisco by Philo Farnsworth, and then publicly by Farnsworth at the Franklin Institute in Philadelphia in 1934, was rapidly overtaking mechanical television. Farnsworth's system was first used for broadcasting in 1936, starting at 400 lines to more than 600 lines with fast field scan rates. RCA demonstrated/transmitted all-electronic TV in 1933.[24] In 1939, RCA paid Farnsworth $1 million for his patents, after ten years of litigation. RCA also demonstrated all-electronic television at the 1939 World's Fair in New York City. The last mechanical television broadcasts ended in 1939 at stations run by a handful of public universities in the United States.

Field tests in Los Angeles on various electronic scanning systems began in 1936. By 1938, the United States adopted RCA's 441-line system. RCA had also evaluated 240- and 343-line electronic scanning before settling on 441 lines. The system was publicly launched by NBC during the New York World's Fair. Because Canadian television came after United States television, Canadians did not have to go through the phase of experimental, mechanical televisions. The 525-line NTSC standard replaced the 441-line standard on July 1, 1941, and opened up the door to the mass production of televisions after WWII in both Canada and the United States.

Servicing

Early televisions had tube counts around 20 to 22. With that many tubes, the mean time to failure decreased so tubes had to be replaced occasionally. The stages most prone to tube failure were the low voltage rectifier and the horizontal output stage. When the television failed, the viewer would typically call up their favorite TV repair shop and place a service call. A technician would then show up at the front door with a tube caddy, such as shown in Fig. 12 and Fig. 13. This was a wooden case with two clamshell-type storage areas in the top third of the case. These clamshells would be stocked with the most popular types of tubes. At the bottom of the caddy, there was space for tools or additional tubes.

Based on experience and symptom recognition, the technician would substitute the most likely failed tube. The tube substitution method was the most

foolproof one, especially when dealing with a tube in the receiver's RF stages. If the technician did not have a tube to substitute, it meant a trip back to the shop. For faults that could not be repaired in the viewer's home, the technician pulled the chassis out of the cabinet in order to bring it back to the shop for a bench repair. That meant the household would be without a set until the chassis was repaired.

Fig. 12. Typical tube caddy ready to carry to the jobsite. They came in several sizes. (Author)

Often, a television owner would become very concerned if the sound was good but there was no light being emitted from the picture tube. Many folks thought that the picture tube went defective. A good technician would assure the owner that the picture tube was the very last one to go.

Just like Saturday morning car mechanics, the TV world also had do-it-yourself folks (DIY) who tackled TV repair. They would look at a symptom chart which would tell them the most likely tubes to check. The suspect tubes would then be taken to a drugstore that was equipped with a tube tester. The tubes would then be tested, and if one

Fig. 13. Tube caddy interior. The bottom part would be filled with tools, and the two parts on the side that fold out would be filled with tubes. A second tube caddy may also be brought along if more tubes were needed. (Author)

was found to be bad, the customer could purchase a new tube from the stock of tubes stored inside the tester. Rumor has it that the drugstore emission type tube testers were biased to show many tubes as being weak or bad when in fact they were perfectly good. However, this has not been corroborated anywhere. With the advent of solid-state TV design came the mass disappearance of TV repair technicians, TV repair shops, drug store tube testers, and do-it-yourselfers.

Sound

Pre-1941 TVs used amplitude modulated sound. The NTSC standard of 1941 directed that TV sound be frequency modulated. Initially, sets were designed to receive FM monaural signals having a maximum deviation of +/- 25 kHz, unlike the FM broadcast band where permissible signal deviation is +/- 75 kHz.

Multichannel television sound, better known as MTS, is the method of encoding three additional channels of audio into an NTSC-format audio carrier. It was adopted by the FCC as the United States standard for stereo television transmission in 1984. Sporadic network transmission of stereo audio began on NBC on July 26, 1984, with The Tonight Show starring Johnny Carson—although at the time, only the network's New York City flagship station, WNBC, had stereo broadcast capability.[25] Regular stereo transmission of programs began in 1985. Canada soon followed suit.

In older TVs, there was sufficient space to install proper permanent magnet speakers in the cabinet. In many of the new flat-screen TVs there is insufficient depth to facilitate proper, inboard speakers. As a result, the audio can sound somewhat "tinny" since the internal speakers are just too small. To address this problem, the viewer must hook up an external audio amplifier and quality speakers in order to achieve good audio fidelity.

Tuners

Early electro-mechanical tuners in televisions consisted of ganged wafer switches which had contacts that were used to select different taps on a coil, thus tuning the receiver to different stations. A wafer type tuner is shown in Fig. 14. Over time, the contacts would become intermittent and the tuner knob would have to be jiggled until the station was tuned in. In really bad cases, a wedge of paper placed behind the knob would stabilize reception. A TV repairman would clean the contacts of oxidation using a product called tuner cleaner, developed specifically for this task, such as shown in Fig. 15. It was therefore not surprising that early televisions only had a life expectancy of perhaps ten years before a seriously intermittent tuner caused the set to be scrapped. Shortly after the wafer type tuner was used, the turret-style tuner was developed specifically for TV usage, such as shown in Fig. 16. Since this also had contacts, it was also subject to the same intermittent contact problems, but in general was more reliable. However all the frequency-determining components were located on the turret strips and assembly time was reduced. In the 1980s, tuners became all electronic. Gone was the clunk, clunk,

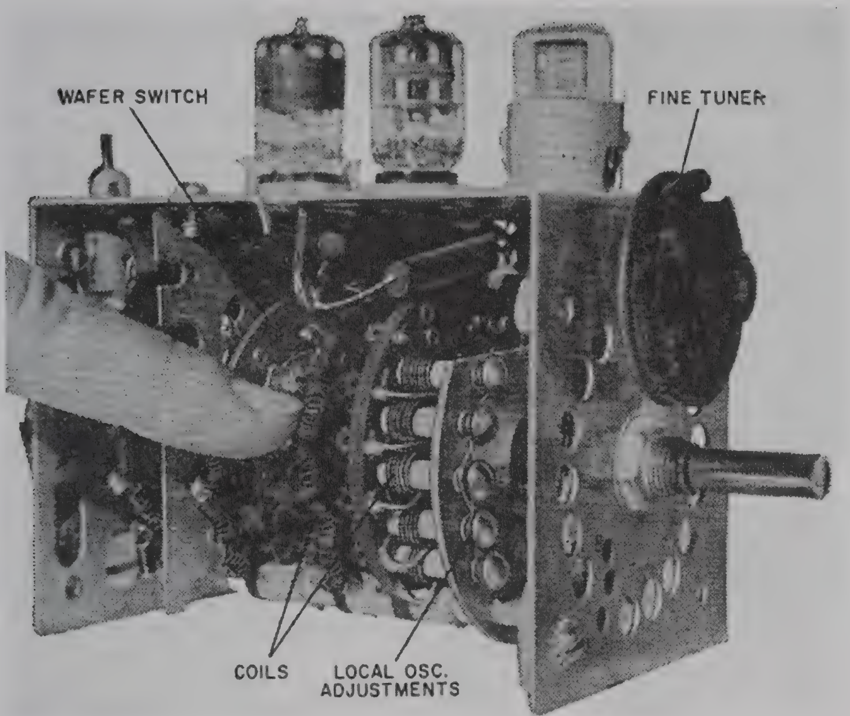

Fig. 14. Wafer type TV tuner. This is similar to a band switch in many multi-band receivers. The wafer type tuner was eventually replaced with the more reliable turret style. The tuner consisted of the RF amplifier(s) and oscillator/mixer stages. The resulting IF signal was fed into the IF amplifier stages on the chassis. (https://www.rfcafe.com/references/popular-electronics/taming-tv-tuner-popular-electronics-march-1967.htm)

clunk sound of the switch-wafer and turret tuner. Also gone was the need for the ubiquitous tuner cleaner to clean TV tuners, but the product has remained, to clean intermittent contacts of all kinds! Advanced formulations were made and renamed contact cleaner.

When UHF television came into being, the FCC allocated channels 14 to 83. The All-Channels Act was passed by the United States Congress in 1961, which allowed the Federal Communications Commission to require that all television set manufacturers must include UHF tuners, so that new UHF band TV stations could be received by the public.[26] This was a problem at the time since the major TV networks were well-established on VHF, while many local-only stations on UHF were struggling for survival. Canadian TV production and programming followed suit.

In 1983, the FCC removed channels 58 through 83 from UHF TV and reassigned them to land mobile radio systems. Television production in Canada made the necessary changes to conform with the U.S. allocations.

Fig. 15. Tuner cleaner, developed to clean TV tuner contacts. Many companies sold such a product, this is a new improved variety. (Author)

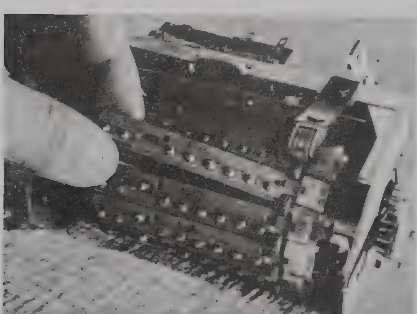

Fig. 16. Turret style TV tuner. This was a new design for TV receivers and was more reliable but still had reliability problems. (https://www.rfcafe.com/references/popular-electronics/taming-tv-tuner-popular-electronics-march-1967.htm)

Canadian Television Production Today

Founded in 1907, Electrohome was Canada's largest manufacturer of TVs from 1949 to 1984. From 1984 to 1999, Electrohome-branded TVs were produced under license by Mitsubishi Electric, and from 1999 to 2007 by Jutan (distributed by Canadian distributor Citizen Electronics). The company underwent an orderly wind-up in late 2008. In February 2010, the Electrohome brand was acquired by Bluetronics Group, a division of Circus World Displays Limited.

All TVs now sold in Canada come from the Far East.

It is hoped that this article gives the reader a glimpse into Canadian television history.

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About the Author

Jerry Proc, VE3FAB, a resident of Etobicoke, Ontario, has been a licensed amateur radio operator since 1964 and also holds an Advanced Amateur Radio Operator's Certificate. His interest in electronics was sparked at a very young age, and during the 1960s Jerry developed a fascination with military radio gear. In 1970, he graduated with a diploma in Electronics Engineering Technology from the Radio College of Canada. Later, he obtained an Advanced Networking Certificate through Continuing Education Studies program at

Humber College, Etobicoke, Ontario. Jerry has served in both a technical and managerial capacity in the mainframe computer and data communications field since 1970 and is currently retired from Bell Canada where he was employed as a network support specialist.

Jerry Proc

The Early History and Products of Centralab Through the 1930s

If you have ever built, used, or serviced consumer, commercial, or military electronics built from the 1920s through the 1970s, chances are good that you have encountered one or more Central Radio Laboratories (CRL or Centralab) products without much notice. Through the decades, Centralab provided a wide variety of discrete component products to the electronics industry as both original equipment manufacturer (OEM) and as repair/substitution parts. While their products did not have prominent nameplate visibility, Centralab products could be found "behind the panel" in virtually any electronic application requiring fixed or variable resistances or capacitors, small inductances, and switches for RF, AC/DC, and audio applications. In the 1950s, Centralab came tantalizingly close to developing the integrated circuit. The following review chronicles the brand's history and achievements from its founding to the days before WWII.

Central Radio Laboratories Origins

Milwaukee attorneys, Frank L. McNamara, John H. Hurley, and Herman E. Friedrich executed articles of incorporation for the Central Radio Laboratories on April 14, 1922. The Wisconsin secretary of state subsequently filed these articles on April 21, 1922, marking the first official day of business for CRL. The Central Radio Laboratories' business intent was the "manufacture and sale of radiotelegraph and telephone parts and equipments." A total capitalization of $20,000 was authorized in the form of 200 shares.[1] Separately, E. R. Stoekle of 298 9th Street was listed as president; Edward H. Myers (1243 Locust St.) was identified as vice president, and C. R. Hammond (of Cutler-Hammer Mfg. Co.) as secretary-treasurer.[2] The distribution of shares is unclear. By virtue of their founder status, it is likely that Stoekle, Hammond, and Myers held shares. McNamara, Hurley, and Friedrich provided legal representation and may have received shares in lieu of incorporation service fees.[3] The first annual report of the corporation, dated March 30, 1923, listed the business address as 303 16th Street in Milwaukee (modern address 1017 N. 16th St.). C. R. Hammond (1400 Grand Avenue) was listed as secretary, and W. E. Sargent (1016 40th St.) as treasurer, but no further mention of Myers. Although the original capitalization was $20,000, only $12,000 of capital had been expended during the first year of operation. Capital expenditures increased to $15,000 by March 1924.[4] By April

10, 1925, capitalization had reached the $20,000 maximum authorized and S. M. McFedries (624 Shepard Ave.) had been engaged as the vice president.[5]

The technical origins of the Central Radio Laboratories can be attributed primarily to Erwin Rudolph Stoekle, the second of three children by Rudolph Benjamin Stoekle (1856–1906) and Matilda (Krueger) Stoekle (1864–1933). Born on June 8, 1891, he spent his childhood years in Chicago with sisters Lydia Matilda (1888–1968) and Sylvia Ruth (1906–1997). Immediately following his father's death on October 15, 1906,[6] the family's movements are uncertain.

Erwin completed his Bachelor's degree with a major in physics and a minor in chemistry at Chicago's Northwestern University in 1911. He subsequently moved to 1113 W. Dayton Street, Madison, WI.[7] As an assistant in physics earning between $450 and $1,025 per year,[8] he completed both his masters (1913) and Ph.D. (1916) in physics at the University of Wisconsin, Madison.[9] His Ph.D. thesis, entitled "Thermionic Currents from Molybdenum," was published in November of 1916, concurrent with a corresponding article in the *Physical Review*.[10] Although not documented, it is more than likely that Stoekle was aware of Professor Edward Bennett and Earle M. Terry's wireless experimentation and the early 9XM broadcasting station, as it was assembled in UW-Madison's Science Hall by the Physics Department in 1915.[11] One of the few known photographs of Erwin Stoekle (Fig. 1) appeared in the UW-Madison's 1916 yearbook in a group photo of the Unity Club, "an organization for liberal religious discussion and social fellowship."[12]

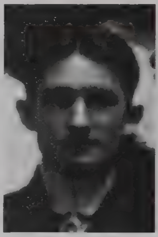


Fig. 1. Erwin R. Stoekle, 1916. (UW-Madison archives)

During the years 1915–1917, concurrent with his graduate work, Stoekle also worked as a research physicist for the Western Electric Company, producing at least one U.S. patent, #1,353,976, for a high heat dissipating vacuum tube device.[13] Sometime in 1917, he apparently relocated to Milwaukee, WI,[14] to work as the director of the Physical Laboratory for the Cutler-Hammer Manufacturing Co. (Fig. 2).[15] This move also reunited Erwin with his mother and younger sister, Sylvia, in Milwaukee. The three shared a home at 298 9th Street (present-day 1020 N. 9th St). His mother Matilda was a teacher and later dean of the Milwaukee University School. His sister was a student at this time (1916–18).

Founded in 1893, Cutler-Hammer (C-H) was primarily a manufacturer of industrial electrical motor starters and controls.[16] As the United States entered the First World War, C-H production shifted to military goods including rifle grenades, in addition to electrical management equipment for a multitude of control and motor/generator operations. With approximately 2,400 employees in 1919,[17] the shift to peacetime products after the war found the company expanding into the manufacture of diverse

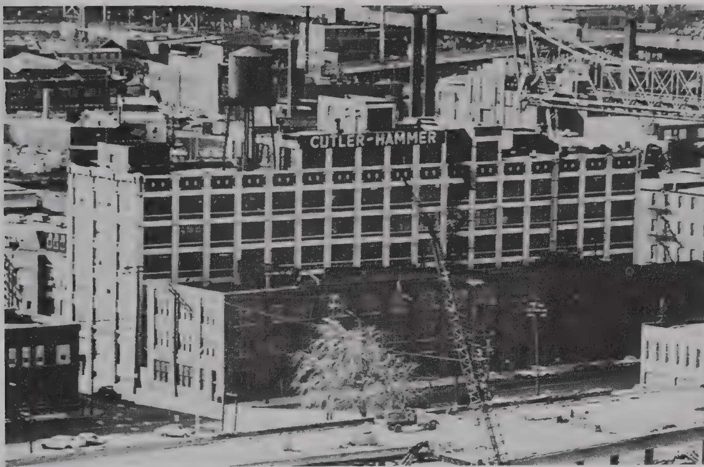


Fig. 2. Cutler-Hammer factory, 1920. (*An American Dream: A Commemorative History of Cutler-Hammer, Inc. 1892–1978*, Cutler-Hammer, Inc. 1979)

products including motor starters, speed regulators, AC and DC controllers, battery chargers, lifting magnets, magnetic clutches and brakes, molded insulator materials (Thermoplax and Pyroplax), and industrial heating equipment.[18] By the early 1920s, Cutler-Hammer had introduced a variety of large, heavy, rather clumsy drum-type variable resistance controls for the fledgling radio industry (Fig. 3).[19] During his tenure at Cutler-Hammer (1917–1922), Stoekle found inspiration for a number of patents. In August 1922, he found time to teach a class on radio through the UW-Madison Extension Division in Milwaukee.[20] A well-worn 1921 edition of the Morecroft text *Principles of Radio Communication* having Stoekle's signature along with the Central Radio Laboratories inscription exists (Fig. 4), which may have been used as a course text

Fig. 3. Cutler-Hammer rheostat, 1922. (*Radio News*, Sept. 1922, p. 571)

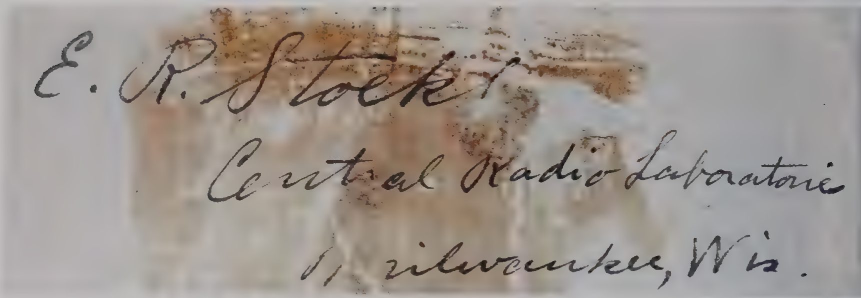


Fig. 4. E. R. Stoekle's signature in his personal copy of *Principles of Radio Communication.* (Author)

and most probably as a working reference. While work at C-H seems to have treated Stoekle well, it appears that he had begun considering his own unique radio apparatus designs during this time, perhaps as improvements to the Cutler-Hammer products. He also apparently made the acquaintance of Messrs. Clifford Hammond and Walter Sargent. Clifford Hammond was identified as a sales manager for Cutler-Hammer as late as 1923. During this same period, Walter Sargent was a department manager for Cutler-Hammer.[21]

Central Radio Laboratories Operations 1922–1924

Based on the evidence in the Central Radio Laboratories articles of incorporation, it would appear that Stoekle, Hammond, and Sargent endeavored to enter the blossoming radio field with their own company in 1922.[22] As with many start-ups, founding information is scant. It appears that Stoekle provided the technical designs, Sargent may have been responsible for their execution, and Hammond likely sold their products. Unfortunately, the actual distribution of investment and shares among the founders is not documented. Except for Stoekle, no photographs of these early entrepreneurs or their business location have been found.

The earliest advertisements for the business appeared in the June 1922 *QST*[23] (Fig. 5) and the July 1922 *Radio News*[24] for the Model 100 panel mounted

Fig. 5. First CRL Model 100 advertisement. (*QST*, June 1922, p. 88)

filament rheostat. The size and graphics of the ad would suggest a substantial company, rather than a new start-up. These early ads and packaging established the Central Radio Laboratories corporate name and the distinctive early diamond shaped CRL trademark, which was to remain with their products throughout the company's life. A latter-day explanation of the trademark was that it not only abbreviated the Central Radio Laboratories name, but also was intended to capture the abbreviations for Capacitance (C), Resistance (R), and Inductance (L).[25] An example of a rare NIB Model 100 and box is shown in Fig. 6. The CRL business address also was identified in the initial ads as 303 16th Street, Milwaukee (present-day 1017 N. 16th Street). Coincidentally, the same address is attributed to the Barbers & Gervais Auto Company, suggesting that CRL was truly a garage shop operation at its origin.[26] Unfortunately, urban renewal of the area in the 1960s completely cleared any structures of interest.

The use of Thermoplax for the molded base of the Model 100 rheostat suggests that the competition with Cutler-Hammer was amicable, as Thermoplax was a cold molded dielectric material promoted by Cutler-Hammer.[27] Since C-H advertised molding services, Fig. 7, it appears that most, if not all of the early molded CRL parts were actually processed at Cutler-Hammer.[28] Although belatedly covered by patent,[29] aside from being an initial product offering, it is unclear if the Model 100 rheostat was intended to be a serious entry into the competitive radio business, as this particular unit does not appear to be significantly different from a host of other contemporary wire-wound filament rheostats. As an introductory product, the Model 100 rheostat advertising was limited to the period between June and October 1922.

The Model 100 rheostat was supplemented/replaced by the Models 101 and

Fig. 6. CRL Model 100 rheostat and rheostat box. (Author)

Fig. 7. Cutler-Hammer Thermoplax advertisement. (*Radio News*, Oct. 1922, p. 797)

102 filament rheostats, which consisted of a somewhat different wire-wound design, as illustrated in Fig. 8 and Fig. 9, with their respective boxes. Although covered under U.S. and Canadian patents,[30] they bear a vague resemblance to the C-H rheostats of the period, and a somewhat striking similarity to those offered concurrently by Kellogg Switchboard & Supply. (Patent for the wire-wound Models 101 & 102 discussed here are United States: 1,461,634 issued July 10, 1923; Canadian: 254,160 issued September 29, 1925. (Note that Canadian Patent 244,956, issued December 2, 1924, corresponds to the groundbreaking U.S. patent 1,448,681 below.) All three designs employed a resistance coil on a rotating drum and fixed wiper design. The first ad for the Model 102 appeared in the October 1922 issue of *Radio News*[31] and was reviewed in the November 1922 issue of *Radio*.[32] The Model 102 provided a vernier fine adjustment control. The Model

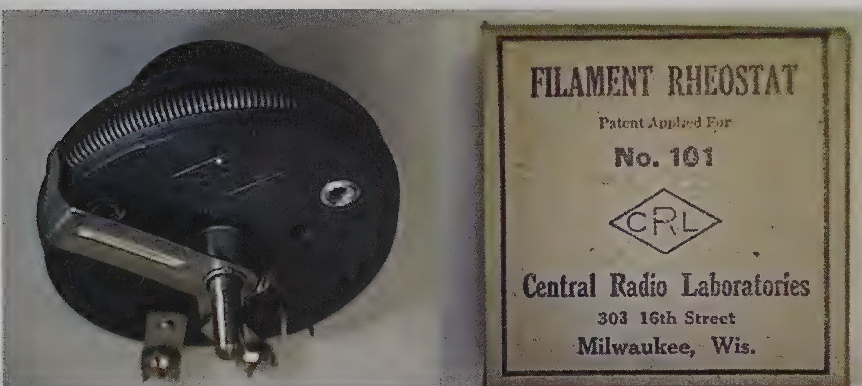


Fig. 8. CRL Model 101 rheostat and rheostat box. (Author)

Fig. 9. CRL Model 102 vernier rheostat and vernier rheostat box. (Author)

101 was identical to the Model 102 but without the vernier control. Apparently, these could be purchased individually or were bulk shipped in boxes of ten pieces (Fig. 10), but it is unclear if they found use in any commercially manufactured radios. The years have not been kind to either model of this design, as the main wiper frequently fatigues, resulting in lost or inconsistent contact with the resistance coil and/or the Model 102 vernier wire grows and loosens from its support. These products were advertised in the short time between October and December 1922. Again, these products seem more like placeholders than novel designs.

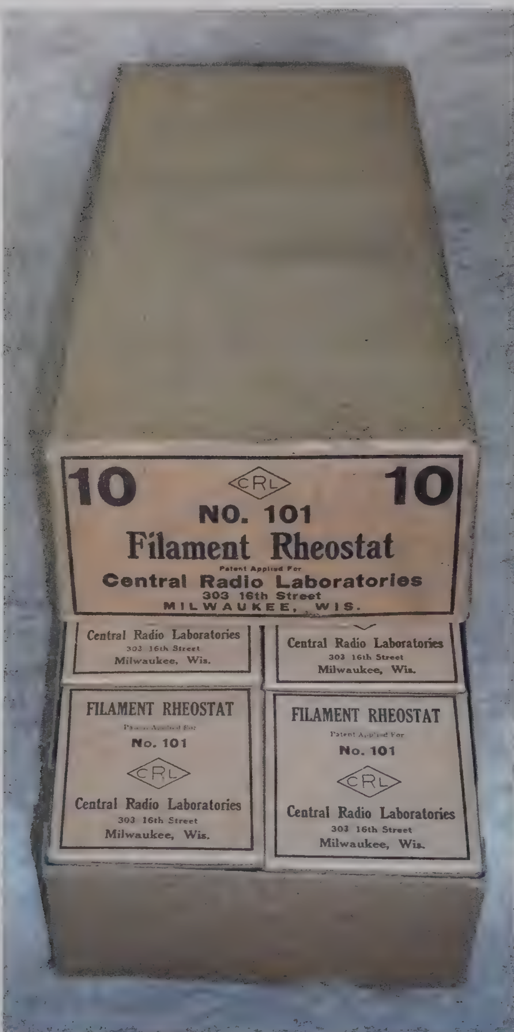


Fig. 10. CRL Model 101 ten piece bulk box. (Author)

U.S. Patent 1,448,681: A Groundbreaking Product

The seeds were sown for one of CRL's most popular and important early products when Stoekle applied for a U.S. patent for an electrical resistor on September 11, 1922. The device generically consisted of a flexible, non-rubbing metallic contactor, a continuous carbon resistance surface, and a movable compression member in several configurations. The patent was issued on March 13, 1923, as number 1,448,681.[33] Two basic configurations were disclosed. A simple bar-shaped compression resistor (Model 106) was described for use in grid leak applications (Fig. 11), which first appeared in the January 1923 issue of *Radio News*.[34] The Model 107 included an added 250 pF capacitor across the two binding posts at an advertised cost of $1.60 vs $1.25 for the Model 106.[35] At one point in 1923, the Models 106 and 107 appear to have been the top selling CRL products.[36] The

Fig. 11. CRL Model 106 compression bar grid leak, side view and rear view. (Author)

second design disclosed in this patent proved to be the foundation for CRL's early success.[37] This design formed the basis for the 2¼" diameter round variable resistances having transparent yellow dust covers found in many mid- to late-1920s radios, shown in Fig. 12.[38] The patented rheostats were promoted as non-inductive, permanently noiseless, and long-lived. The Centralab rocking disc contact volume control employed a movable arm-mounted pressure point that pressed a rocking metal plate into contact with a stationary graphite surface to produce a variable resistance, virtually eliminating the pops, crackles, and dead spots encountered with contemporary wire-wound controls. The resistance element was not subject to the mechanical wear of wiper contacts. It was also promoted as non-inductive, based on the absence of coiled resistance wire found in many competitive pots and rheostats. The earliest models, 110 and 111, representing different maximum resistance values, were popular CRL products soon after introduction.[39] This design was also the subject of a slightly later Canadian patent, number 244,956, issued December 2, 1924. Given the importance of this device and the variety of configurations, some of the design changes will be investigated later.

A second patent, issued on July 10, 1923, described a wire-wound rheostat for the control of up to six quarter-ampere tubes (Fig. 13). The design intent was to lock the resistance wire in place by compressing the wire between two asbestos pads to prevent any wire movement that would produce hysteresis or shorting. Its construction was reported to be heat resistant.[40] The Models 206 and 230 were impressive with large, bright plated endplates.[41] While many

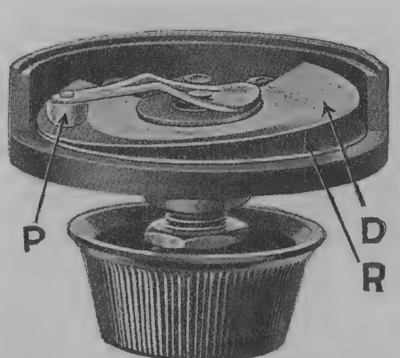


Fig. 12. CRL non-inductive Radiohm construction. (*Volume Control Guide for Service Men*, Centralab First Edition, 1930)

examples still survive, it apparently suffered from some unanticipated technical limitations. More than one example has been observed with burned out internal resistance supports, allowing the wire windings to float freely, suggesting that heat dissipation was less than optimum with the "sandwiched" design. This design was superseded no later than 1926, when a ribbon of resistance metal was introduced for some applications and the overall design altered to allow improved heat release (Fig. 14).[42]

Fig. 13. CRL Model 206/230 chrome filament rheostat, ca. 1923. (Author)

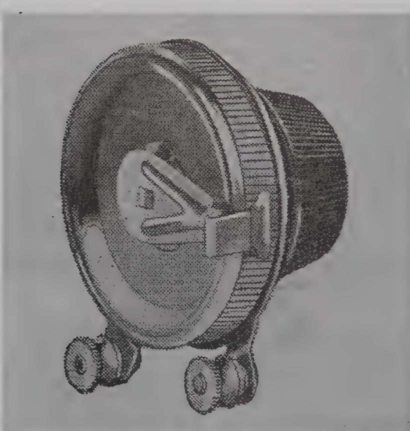


Fig. 14. Centralab improved filament rheostat. (*Tone and Volume Control*, Centralab Form 291, July 1926)

1920s Business Considerations

Surviving examples of a trial balance sheet and an operating statement, both dated October 31, 1923, are shown in Table 1 and Table 2, respectively. These statements give some insight into the income and expenses of the new venture. It is unclear what statement period is covered, although the operating statement[43] appears to be a monthly summary and the trial balance sheet[44] appears to be an annual or six-month summary. One listed item relates to a number of products sold, approximately 10,500 pieces, and their average production cost, which appears to be just short of $0.68 per unit versus a minimum selling price of $1.50. The Model 107 and Model 106 grid leaks, and the Model 110, a 400 ohm Radiohm, accounted for the majority of products sold. It also appears that some portion of the production may have been sold to Howard Radio and Marco. A small volume (50 pieces) part number 108 is also indicated, but has not been identified in any advertisement

The product mix through 1924 consisted of the compression grid leak and variable resistors, the nickel-plated wire-wound variable resistors, and the short-lived Model 300 battery switch (Fig. 15).[45] While Central Radio Laboratories advertised extensively and elaborately in *Radio News* and *QST*, no new unique products were offered. The September issue of *Radio News* announced

Table 1. CRL Trial Balance Sheet transcription, October 31, 1923.

Current assets

Cash: national exchange		2070.83	
Petty cash		16.94	
Bills receivable		819.88	
Accounts receivable	7530.56		
Less reserve	445.02	7085.54	
Inventory		7522.01	17515.2

Current Liabilities

Accounts payable		3219.79	
Commissions payable		955.53	4175.32

Current assets over liabilities 13,339.88

Deferred assets

Patents			3765
Machinery		950	
Tools, jigs & dies		1011.6	
Small tools		520.49	
		2482.09	
Less reserve		983.38	
		1498.71	
Office furniture & fixtures		200	
Printing & stationery		25	
Insurance pre paid		79.5	
Advertising pre paid		550	2353.21
			19,458.09

Deferred liabilities

Capital stock		20000	
Less treasury		8000	12000
Due officers & directors			4020
Reserve taxes & legal			500.99
Surplus account			2937.1
			19,458.09

Table 2. CRL Operating Statement transcription, October 31, 1923.

Sales (all numbers are $)		7135.95
Cost Sales Labor & Materials	3349.44	
Reserve Bad Debts	145.14	
Commissions	563.33	
Interest & Discount	61.87	4119.78
		3016.17

Royalties Howard Radio		178.75
Royalties Marco		430.80

Reserve for Taxes & Legal	250.00	
Reserve for Machinery	14.25	
Reserve for Tools, Jigs & Dies	20.23	
Reserve for Tools, Jigs & Dies	285.00	
Reserve for Small Tools	52.05	
Advertising	337.19	
Office Expenses	71.24	
Heat, Light & Power	82.67	
Salaries	1595.00	
Shop Expenses	47.95	
Printing & Stationery	10.50	
Insurance	10.50	
Patents 1/17	235.00	
	3011.58	
October Gain to Surplus	614.14	
	3625.72	3625.72

Handwritten notes

2756	#106
6552	#107
50	#108
994	#110
152	#111
10504	

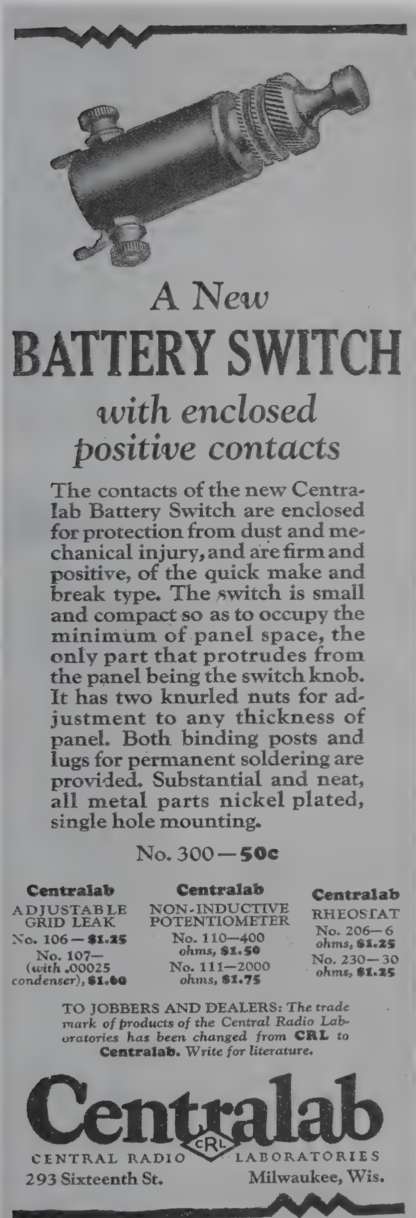


Fig. 15. CRL Model 300 battery switch. (*Popular Radio*, Oct. 1924, p. 90)

a notable change, as the Centralab name (an interesting contraction of Central Radio Laboratories) became the official trademark of Central Radio Laboratories, displacing the simple CRL diamond. Centralab above a small centered CRL diamond started to appear prominently in their ads.[46] This change was likely done to establish "Centralab" as a more simplified, readily recognized brand name. Separately, but most importantly in 1924, the company's annual meeting records reported that the full initial capitalization of $20,000 had been spent by this time.[47]

Years of Change, 1925–1929

The year 1925 proved to be one of both business and personal changes for CRL and Erwin Stoekle. Centralab introduced the "Radiohm" name for its expanded line of non-inductive rocking disc potentiometers, priced at $2.00, for variable resistances covering 2,000 ohms to 200,000 ohms.[48] Most visible were the dramatic changes in the CRL advertising that occurred during the period between January and April, when the large illustrated ads were replaced by a small single inch column ad showing only name and location. The Central Radio Laboratories/Centralab product offerings through early 1925 are summarized in Table 3.

It was reported at the Globe Electric Co. executive committee meeting held on April 22, 1925, that Mr. McFedries of CRL had approached C. O. Wanvig (vice president of Globe Electric Co.) on the possibility of taking over the CRL business. It was noted that the business had changed from straight jobbing to

Table 3. Early product summary, 1922–25. (* indicates prices reduced by January 1925, to $1.25 and $1.60 for Models 106 and 107 respectively.)

Part Number	Description	Fig.	Price	First Appearance	
				Month	Year
100	Wire-wound rheostat	6	$1.00	June	1922
101	Wire-wound rheostat	8		October	1922
102	Wire-wound rheostat with vernier	9		October	1922
106	Adjustable grid leak	11	$1.50*	January	1923
107	Adjustable grid leak with 25pF cap		$1.85*	January	1923
110	Non-Inductive rheostat 400 ohm	12	$1.75	November	1923
111	Non-Inductive rheostat 2000 ohm		$2.00	November	1923
206	Wire-wound rheostat 6 ohm	13	$1.25	September	1924
230	Wire-wound rheostat 30 ohm		$1.25	September	1924
300	Battery switch	15	$0.50	October	1924
2M	Radiohm potentiometer, 2000 ohm		$2.00	February	1925
50M	Radiohm potentiometer, 50,000 ohm		$2.00	February	1925
100M	Radiohm potentiometer, 100,000 ohm		$2.00	February	1925
200M	Radiohm potentiometer, 200,000 ohm		$2.00	February	1925

principally furnishing parts to OEM customers. Consequently, the CRL facilities were inadequate to meet the increased production needed for the 1925 business. It was also stated that McFedries was relocating to California and desired to sell his interest in CRL. Globe would also obtain the services of Dr. Stoekle.[49] By May 6, 1925, Globe executives agreed to purchase a one-half interest in CRL with an option to purchase the balance at the expiration of one year, as proposed by CRL on April 29.[50] The CRL shareholders agreed to adopt this arrangement at a special meeting on May 18.[51] The following day, C. O. Wanvig and J. D. Wanvig, Jr. were elected as CRL vice president and secretary, respectively, at a second special CRL stockholders meeting, replacing McFedries and Hammond.[52] On May 20, contracts for the purchase of the balance of all outstanding shares of CRL stock were executed by Globe Electric at the Globe executive committee meeting.[53] Manufacturing of CRL products commenced at Globe's Keefe Avenue plant (Fig. 16) on May 22,[54] and the move of all CRL operations had been completed by May 26.[55] The Central Radio Laboratories' annual meeting of 1925 marked a change in management and ownership.[56] Related meeting correspondence, dated June 9, 1925, indicates that the business address was changed to 16 Keefe Avenue, Milwaukee (present-day 900 E. Keefe Ave.).[57] E. R. Stoekle apparently retained his title as CRL president. Globe stockholders ratified final approval of the CRL purchase on July 6, 1925.[58]

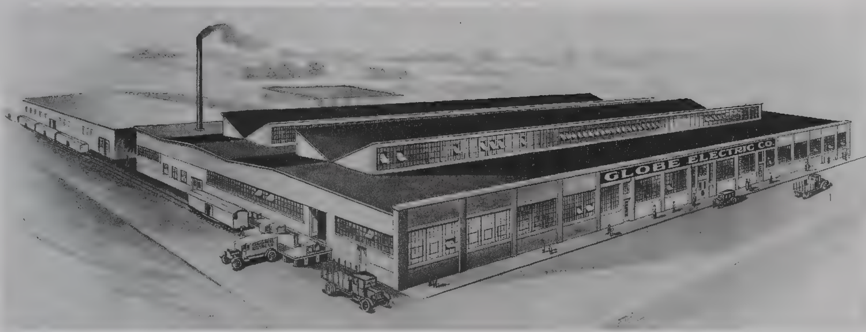


Fig. 16. Globe Electric Company Keefe Ave. plant early 1920s. (Globe Electric Company, *Radio Bulletin 25*, undated, ca. 1924)

The Wanvig brothers were the principal owners and executives of the Globe Electric Company, a Milwaukee manufacturer of lead-acid batteries for automotive and stationary power, farm power plants, control panels, and battery operated radios, also located at the Keefe Avenue address. With the acquisition of CRL, it appears that Globe decided to exit the radio manufacturing business, offering their last models in 1926.[59] Over the next decade, Stoekle and the Wanvig brothers remained constants throughout the Central Radio Laboratories organization.

Personally, Erwin Stoekle was retained as the CRL technical expert with an apparently improved income. He, Matilda, and Sylvia relocated to 507 Belleview Place on Milwaukee's east side, a definite improvement in neighborhood.[60] During this same period, it appears that Erwin also met and married Lillian Knell, his lifelong spouse.

Following Globe's acquisition and a break of nearly a year, around May 1926, more modest CRL advertising resumed in a wider range of publications in addition to *QST* and *Radio News*, including *Broadcast Radio* and *Citizens Radio Broadcast*, using the new Keefe Avenue address. Although CRL/Centralab published a variety of pamphlet product literature in the 1920s, the lack of consistent numbering and the frequent absence of publication dates complicate definitive identification of many product introductions. The year 1926 appears to have been primarily a reorganization period, however two notable products were introduced. First, the Modu-pluG was advertised as a means to "remotely" control horn/cone speaker volume via a hand-held in-line rocking disc variable resistor. It was available in either a ¼ inch phone plug or corded versions.[61] Its appearance along with its interior construction and packaging is illustrated in Fig. 17 and Fig. 18.[62] The development of battery eliminators and AC operated radios resulted in the introduction of the "Heavy Duty Radiohm."[63] Outwardly this device appears identical to the clear-backed Radiohms except that the rear dust cover is opaque black Bakelite. It was rated at 3 W and specifically

intended for use in B eliminators. As advertised, Raytheon approved the unit. The ad also indicated that Centralab had foreign offices in Canada, Great Britain, and Australia. The rest of the product line consisted of clear-backed Radiohms, ranging from 2,000 to 200,000 ohms, volume controls (modulators) of 200,000 and 500,000 ohms, and related potentiometers and rheostats. An example of the Radiohm in its late 1924 to early 1926 configuration is illustrated in Fig. 19.[64] Continuing its most recent path as an OEM supplier, many Centralab variable resistors found their way into consumer radios. Although most retained the Centralab branding, one example has been found in which the Centralab identification was replaced with a hot stamped "Licensed by Bremer Tully" statement in place of the Centralab name.

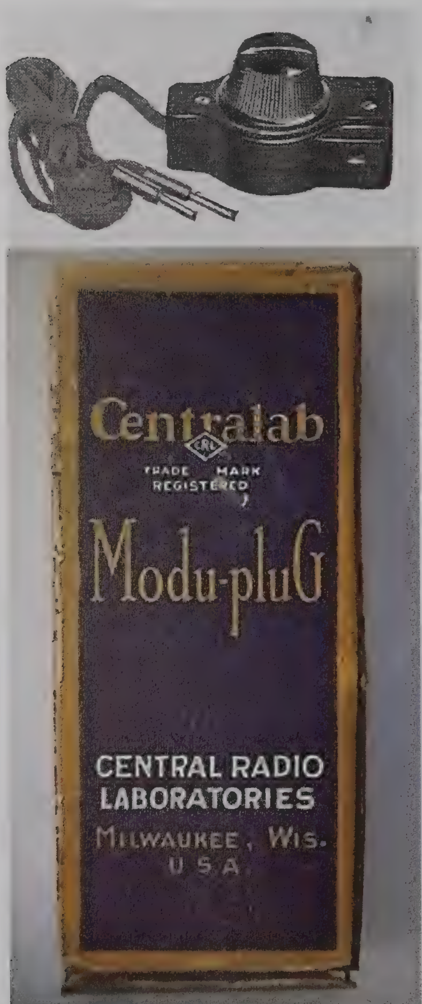
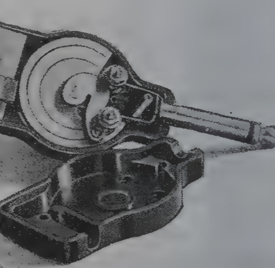


Fig. 17. 1927 Modu-pluG, appearance and box. (*Resistances for Volume Control and Voltage Control*, Centralab Form 417 ca. 1927; author)



New Developments in Radio Apparatus

(*Continued from page* 1648)

tral arm which travels around the plate. This arm short-circuits some of the resistance, which is relatively high, and thereby causes an increase in volume. The tips of the phone cords are inserted in the end of the plug-in the customary fashion.

Although this accessory may seem relatively unimportant, those fans who have

This shows the interior of the phone plug which will vary the volume. The rheostat, has a high resistance.
Courtesy of Central Radio Laboratories.

done much experimenting with different loud speakers and who are very particular about the quality of reception, will agree that a thing of this nature is a handy adjunct to have about the radio receiver. The quality of the reception can, many times, be vastly improved by the addition of a little more resistance in the loud speaker circuit, and here is an easy way to do it.

Fig. 18. 1927 Modu-pluG interior construction. (*Radio News*, June 1926, p. 1698)

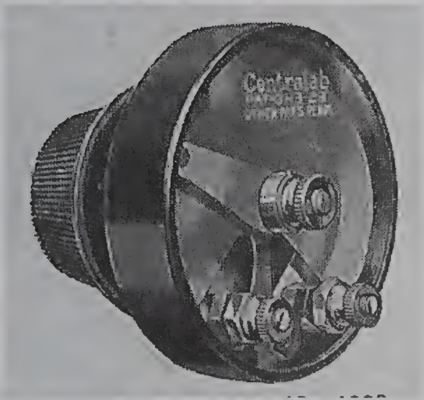


Fig. 19. Centralab Radiohm, late 1924 to early 1926. (*Modulator Potentiometer Radiohm*, Centralab Form 100C, Jan. 1926)

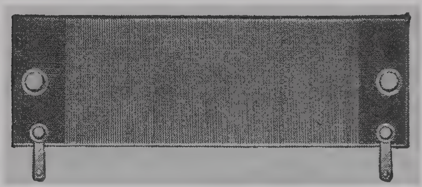


Fig. 20. Wire-wound fixed resistor, 1927. (*Resistances and Their Function in Radio Circuits*, Centralab Form 328, Sept. 1927)

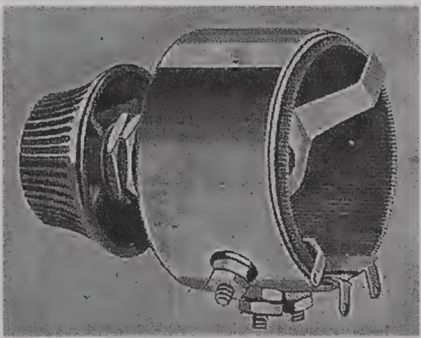


Fig. 21. Heavy duty potentiometer, 1927. (*Resistances and Their Function in Radio Circuits*, Centralab Form 328, Sept. 1927)

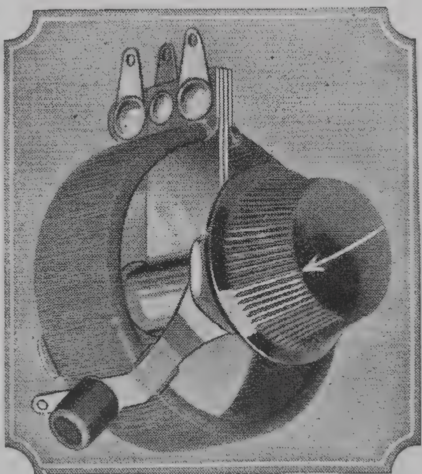


Fig. 22. Tapped wire-wound power potentiometer, 1927. (*Resistances and Their Function in Radio Circuits*, Centralab Form 328, Sept. 1927)

With the infusion of Globe Electric capital and manufacturing resources, the variety of Centralab products blossomed in 1927, reflecting the general philosophy of the new management: If it makes money, we will make it. Accordingly, the product line grew in terms of potentiometer and rheostat resistance ranges and power ratings, as well as the introduction of fixed (Fig. 20) and tapped wire-wound resistors (Fig. 21 and Fig. 22) for A and B power supplies.[65] The wire-wound power potentiometers and rheostats came in three ratings: 25, 50, and 75 W. All were 2 inches in diameter and are easily identified by the depth of the resistance winding, ½, 1, or 1½ inches, respectively. The resistance wire was wound on an asbestos wrapped steel core for high heat tolerance. They can be identified by the Centralab name stamped on the contact arm or the contact arm support. The basic clear-backed variable resistor production continued apace. Varieties with and without integrated switches were

offered. A curious radio station selector switch, priced at $1, was also offered to improve selectivity. It consisted of a cylindrical wood body enclosing a simple on/off switch to introduce an additional inductance into the antenna circuit. Its appearance, interior construction, and packaging are shown in Fig. 23 and Fig. 24.[66]

One of the most unusual products, introduced in 1927, was the Centralab Model 100 Tone Amplifier (Fig. 25). The nameplate is more clearly shown in Fig. 26 and the interior construction documented in Fig. 27 and Fig. 28. Unlike the individual passive components offered to date, this device was intended to plug into a radio's final amplifier tube socket and operate a '71A tube that was located in the tone amplifier. The intent was to modify the horn speaker output into a more pleasing rendition. *Radio News* featured this product in its August 1927 issue, publishing a schematic and description of its operation (Fig. 29).[67] This is of value to today's collector, as the components were individually mounted to the front and

Fig. 23. Antenna selector, 1927, appearance and box. (Author)

Fig. 24. Antenna selector, 1927, interior construction. (Author)

Fig. 25. Tone amplifier, 1927, appearance. (Author)

top panel interiors of the small inaccessible wood cabinet. All components were sourced from external manufacturers except for the Centralab volume control. Curiously, this is the only “active” device that Centralab offered for the next quarter century.

The 1928 product line expanded minimally to include a Radio Control Box to address the migration from battery operation to AC line sources. This device was a variable wire-wound 60 ohm, 25 W rheostat in series with an AC outlet packaged in a 3 × 4 × 1½ inch black metal box with a 6 foot twisted power cord, selling for $3. The purpose was to adjust the AC line voltage to 110 V for the new AC operated radios (Fig. 30 and Fig. 31).[68] Adjustment could be accomplished in two ways with the

Fig. 26. Tone amplifier, 1927, label. (Author)

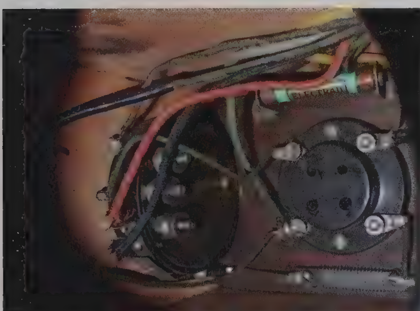


Fig. 27. Tone amplifier, 1927, front interior construction. (Author)

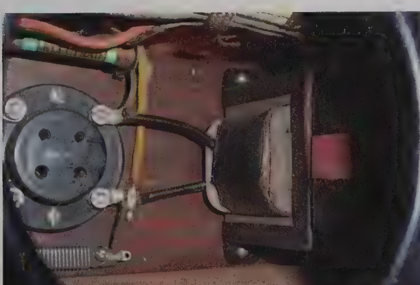


Fig. 28. Tone amplifier, 1927, rear interior construction. (Author)

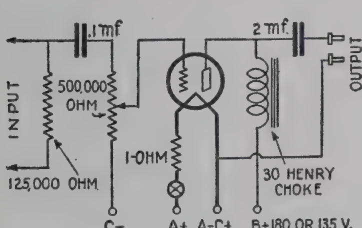


Fig. 29. Tone amplifier schematic, 1927. (*Radio News*, Aug. 1927, p. 118)

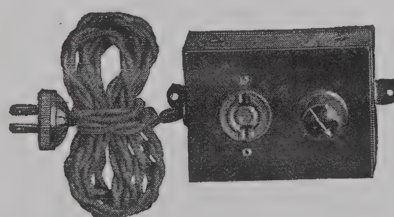


Fig. 30. Radio Control Box, 1927, appearance. (*Resistances for Volume Control and Voltage Control*, Centralab Form 417 ca. 1928)

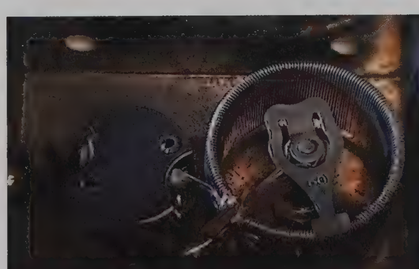


Fig. 31. Radio Control Box, 1927, interior construction. (Author)

operating AC radio connected to the control outlet. If a voltmeter was available, the radio plug was to be partially removed from the outlet and the voltmeter probes touched to the partially exposed plug blades to measure the voltage while adjusting the rheostat. If a voltmeter was not available, the radio was tuned to a moderately loud station and the adjusting knob turned counterclockwise until the volume started to fade.[69]

By June 29, 1929, the parent corporate identity was changed from Globe Electric Co. to Globe-Union Manufacturing Company, reflecting the diversity of product offerings of the parent as well as consolidation with the Union Battery Company of Chicago, also controlled by C. O. Wanvig.[70] This year also marked the introduction of ceramic fixed resistors to the CRL product offerings.[71] These devices purportedly offered improved stability over other contemporary competitors. A "dual volume control" using the rocking disc variable resistance principal was introduced (Fig. 32).[72] The 1920s closed with a wide and expanding variety of fixed and variable resistance products, many employing the principles patented in 1923, as well as products designed for OEM and commercial use. A comprehensive booklet titled *Volume Controls and Voltage Controls – Their Use* made its first appearance (Fig. 33).[73] It not only described the product line, but also presented an overview of circuit applications and suggested the appropriate product. This would be the most comprehensive single source discussion of Centralab product applications prior to the introduction of the *Centralab Volume Control Guide* series in 1930.

Fig. 32. Constant resistance control, 1927, interior construction. (*New Controls Constant Input Resistance Phonograph Pick-Up "Fader,"* Centralab pamphlet, undated, ca. 1929)

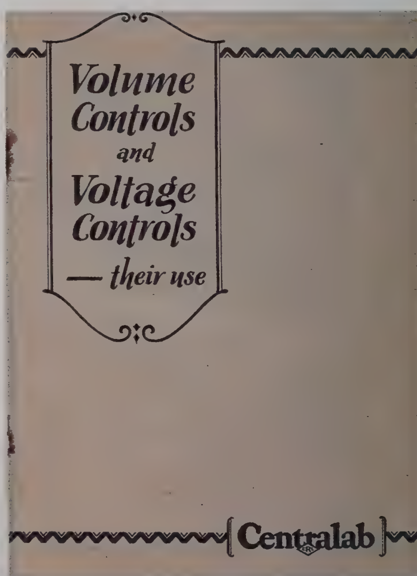


Fig. 33. *Volume Controls and Voltage Controls* booklet, the predecessor to the *Volume Control Guide* booklet. (Author)

Radiohm Design Variations

Given the importance and longevity of the rocking disc variable resistor, examination of the design development and product variations is appropriate. The following photos have been included to illustrate design variations/improvements to the Radiohm originally patented in March of 1923. Dust covers have been removed to more clearly see the internal design changes.

The earliest and least found versions of this control can be identified by the CRL diamond logo stamped on the metal rocker plate and plain plastic dust cover with a center hole (Fig. 34). The wiper arm was a solid piece of plated metal in direct contact with the rocking plate. The arm is held on the shaft with a knurled nut (~0.35 inch diameter) that extended beyond the dust cover. To panel mount the unit, the nut and arm needed to be removed, as the pointer knob was permanently molded on the shaft. The knob design appears to be identical to the previous Model 101 units. Connection to the unit was made exclusively through binding posts having small (~0.28 inch diameter) knurled nuts. This design was first advertised in 1923,[74] and received Radio News Merit Citations 433 and 434 for the Type 110 (400 ohm) and Type 111 (2000 ohm) models in the June 1924 issue.[75] The scarcity of this design today suggests that they may not have fared well due to wear and mechanical abrasion between the pressure arm and the rocker plate.

The first design improvement (Fig. 35) is distinguished by having an insulating pressure peg (~0.18 inch diameter) at the end of the movable pressure arm. The knurled arm retaining nut and center hole dust cover were retained; however, panel mounting was simplified by employing a setscrew knob removable from the front. The CRL diamond remained imprinted on the rocking disc. This design is clearly illustrated in the October 1925 issue of *QST*.[76] The plain brown boxes were replaced by a rarely seen white trimmed violet box with

Fig. 34. First Central Radio Laboratories Radiohm, no pressure peg. (Author)

Fig. 35. Second Central Radio Laboratories Radiohm, small pressure peg. (Author)

prominent CRL markings on each side and part descriptions on top and bottom flaps (Fig. 36).

After the 1925 change in ownership, the CRL imprint was removed from the rocker plate and the identification transferred to the plastic dust cover by hot stamping (Fig. 37). The wording was "Centralab; Pat.-3-13-23; OTHER PATS PENDG." Electrical connections were through binding posts throughout this version, although some, presumably later, variations may have included soldering lugs at the front of the body. During this period, the packaging was changed again, this time featuring an orange and violet motif that was continued into the early 1930s. Early boxes used the orange and violet color scheme on the top and all sides. Later versions contained brief product information texts on opposing sides of the box. Later box tops featured a large white background. One later example was fortuitously dated by the original recipient in 1932, making dating definitive. Examples of the two opposing information box sides from this Radiohm box are shown. The information varies with the product type, e.g. Standard Radiohm, Heavy Duty Radiohm, or Modulator.

Fig. 36. Violet & white Central Radio Laboratories box, ca. 1924–5 showing box ends. (Author)

Fig. 37. First Centralab Radiohm, ca.1926, with small peg and plain rocker plate, showing hot stamped back, corresponding box top and side, and ca. 1932 descriptive box sides. (Author)

The third commonly found configuration (Fig. 38), appearing in 1927,[77] employed a much more robust junction between the shaft and arm. A larger cross-section of metal along with a cutout strain relief was implemented to prevent fatigue of the arm. The arm was staked directly to the shaft, eliminating the knurled nut retainer and allowing the use of a solid dust cover. The pressure peg at the end of the arm was increased to a 0.3 inch diameter to provide a more uniform application of pressure on the rocking disc. The binding post and solder lug combination was used in all models. The identification on the dust cover was

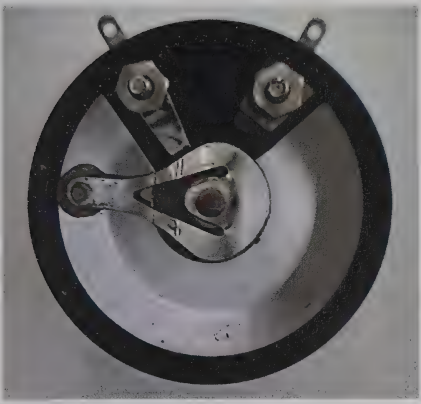


Fig. 38. Second Centralab Radiohm, staked arm with strain relief. (Author)

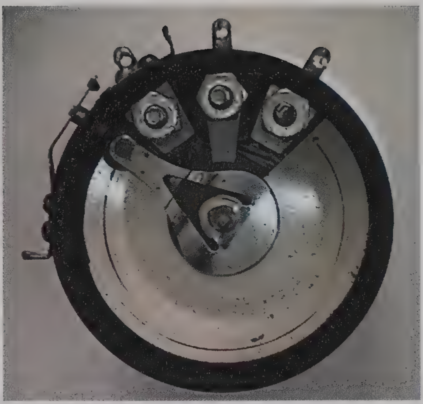


Fig. 39. Centralab Radiohm Model RS with side mounted battery filament switch. (Author)

identical to the previous version except for the added phrase "MADE IN USA." The identification is found in the lower third of the dust cover on some examples, but in other, presumably later examples, it was relocated to the center of the dust cover. The use of the larger diameter pressure point facilitated the inclusion of a side mounted filament switch for battery sets (Fig. 39), identified as a Model "RS."[78]

Two Radiohm versions were produced which reportedly passed 100,000 rotations with little change in original resistance. The Radiohm, serving as a rheostat, had two terminals and was available in five linear taper ranges from 0–2,000 ohms to 0–500,000 ohms. The second version was the potentiometer/modulator, which sported three terminals. Six potentiometers covering ranges from 200 to 100,000 ohms maximum were available. Two modulators of either 250,000 or 500,000 ohms were offered. The resistance tapers of the modulator products were non-linear and designed specifically for volume control applications. Prices for all types ranged between $2.00 without the switch to $2.30 with the filament switch.[79] The original design was widely used by OEM radio manufacturers between the late 1920s and early 1930s, one ad bragging that some 69 manufacturers were using Centralab variable resistances.[80]

In later years, the clear back was replaced by a staked metal dust cover with the Centralab name and patent date imprinted on it, either centered or in the lower section. The binding post connections were eliminated, and electrical connections were made through soldering lugs riveted to the internal resistance components (Fig. 40). The metal dust cover proved to be important for the mounting of future on/off switches; one early configuration from ca. 1930 is illustrated in Fig. 41. Subsequently, the Centralab name was molded into the front of the Bakelite housing. While the diameter of the standard variable resistor was reduced several times in the early 1930s,

the product design principle was basically unchanged for nearly a decade until the need to fit tighter spaces for OEM and repair applications dictated a major design revision. The standard 2¼ inch diameter product was last mentioned in the 1933 *Volume Control Guide.*[81]

Fig. 40. Centralab Radiohm with metal back dust cover removed, riveted solder lugs. (Author)

Fig. 41. Centralab Radiohm with metal back and power switch. (Author)

Developments of the 1930s

The early 1930s were marked primarily as years of change and survival through limited advertising and promotion of both OEM and replacement parts. Advertising started to transition from purely technical descriptions to promotion of quality, reliability, and performance. Some ads tended to be humorous and others relied on testimonials (ca. 1937). The character "Mr. Centralab" first appeared in the June 1935 *QST.*[82] Through subsequent issues, he morphed into "Old Man Radiohm,"[83] the "Ol' Smoothy,"[84] and "Old Man Centralab."[85] Finally, Old Man Centralab grew a rather full mustache by November of 1936,[86] a character (Fig. 42) that would periodically appear in ads for the next 5–6 years.[87] In addition to an expansion of the existing product lines, reduced physical dimensions of variable resistors and growth of ceramic products continued. No attempt will be made to describe all products and variations during this period of dramatic product expansion.

Fig. 42. Old Man Centralab advertising mascot. (*Volume Control Guide*, Centralab Form 1120, May 1940, p. 189)

The most significant product additions or discontinuations will be highlighted.

This period saw the introduction of the Centralab *Volume Control Guide*, initially offered as a 25 cent publication "exclusively for servicemen" in early 1930. A copy of the earliest known ad and an illustration of the first edition of the *Volume Control Guide*[88] are shown in Fig. 43 and Fig. 44. As distribution was restricted to servicemen and business requests on appropriate letterhead, this edition is rather elusive. It appears that the information sheets formerly enclosed with each Radiohm were inconsistently used after the appearance of the first *Volume Control Guide* in which the detailed circuit descriptions had been consolidated.[89] Given the less technical product descriptions in print advertising, which emphasized quality and humor, the successive editions of the Centralab *Volume Control Guide* provided much information regarding new and continuing products through the 1930s. The known *Volume Control Guides* and some related statistics are compiled in Table 4. Editions between 1930 and mid-1933 included discussions of circuit applications in addition to extensive product descriptions and the replacement volume control information by manufacturer. Product highlights in this first edition are the expanded series of variable resistor sizes: Senior/Standard (2¼ diameter base), Junior (1¾ inch diameter base), Fig. 45, and Elf (1½ inch diameter base for "tight" low power uses), Fig. 46. A Midget product was also listed for use only in phono pick-up applications where resistance tapers were "very non-critical."

Fig. 43. First advertisement illustrating the *Volume Control Guide.* (*QST*, May 1930, p. 76)

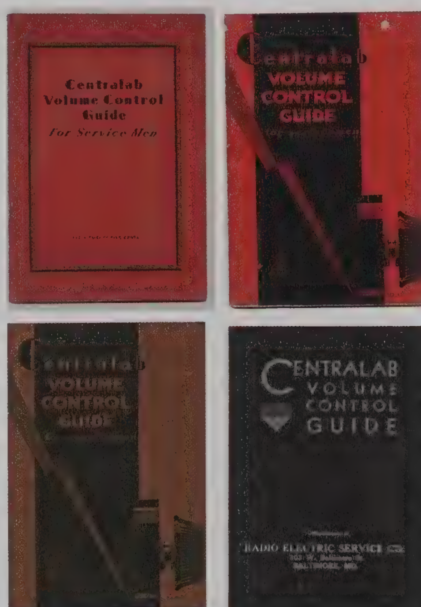


Fig. 44. *Volume Control Guides:* 1930, August 1931, May 1932, December 1933. (Author)

Table 4. Volume Control Guide summary, 1930–39. (* indicates supplement.)

Year	Publication Date	Total Pages	Application Pages	Radio Pages	Product Pages
1930	4/30	32	8	8	16
1931	8/31	48	11	14	23
1932	5/32	64	10	31	23
1932	11/32	64	9	32	23
1933	4/33	64	9	32	23
1934	12/33	32	0	22	10
1935	3/35	64	4	29	31
1936	2/36	93	5	66	22
1937	2/37	168	4	134	30
1937*	12/37	11	0	6	5
1938-9	6/38	240	5	190	45
1939*	7/39	78	0	54	24

By 1934, the Elf product seems to have disappeared and the Standard replacement Radiohm was reduced to 1⅛ inch diameter.[90] By 1937, the Midget nomenclature applied to the small 1⅛ inch diameter replacement volume control.[91] The Radiohm clear plastic dust cover has been replaced by a staked steel cover and a variety of switch configurations, as previously described.[92] Ironically, the price of the *Volume Control Guide* was increased from 25 cents to 50 cents in April of 1932. By December 1933, the size and content of the 1934 edition was significantly reduced and offered for free.

In addition to the *Volume Control Guide* series, product catalogs (designated Form 1001), consisting of 4–12 pages in 8½" x 11" format were produced, the earliest observed issue dating to April 1932, although earlier editions may exist. It provided a comprehensive summary of Centralab products: Standard, Junior, and Elf volume controls, heavy duty potentiometers, power rheostats and potentiometers, L-pads rated between 1 and 25 W, T-pads, faders, fixed dog-bone resistors, the Modu-pluG, and the Radio Control Box.[93] In subsequent years, page count increased and catalog numbers were assigned to variously dated Form 1001 issues, for example, Catalog No. 20-1938-39 is dated June 1938. These product sheets appear to have been issued at least annually and were published at least through the 1930s, possibly beyond. Separate corresponding price list sheets were issued that allowed for simple price adjustments without reprinting the entire publication.

While the next several editions of the *Volume Control Guide* offered very

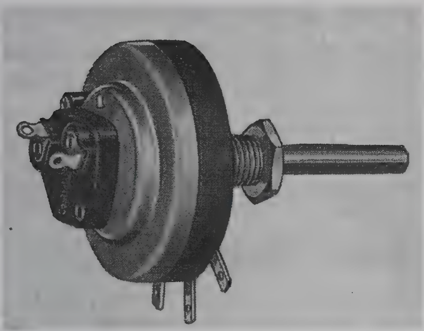


Fig. 45. Junior Radiohm potentiometer with switch. (Centralab Form 1001, Apr. 1932)

similar size and contents, several noteworthy items appeared. Although Parsons reported the production of fixed ceramic resistors as early as 1929,[94] the August 1931 *Volume Control Guide* introduced the new Centralab fixed resistor products, which consisted of a ceramic resistance element surrounded by a hard, dense ceramic casing, fired at over 2,500°F.[95] The first ad for this product appeared in the January 1932 issue of *QST*.[96] The entire production process is described in a separate booklet entitled *A Baptism of Fire*.[97, 98] The first versions of the 310 and 316 resistors were RMA color-coded and featured radial leads approximately 1½ inches long. Apparently Centralab had some difficulty in determining the appropriate power rating for these products. As summarized in Table 5, although fixed resistors remained dimensionally unchanged, reratings occurred several times throughout the product history. Initially, packs of ten resistors could be ordered containing customer selected values and quantities, making a mixed pack. That quickly changed to ten packs of a single

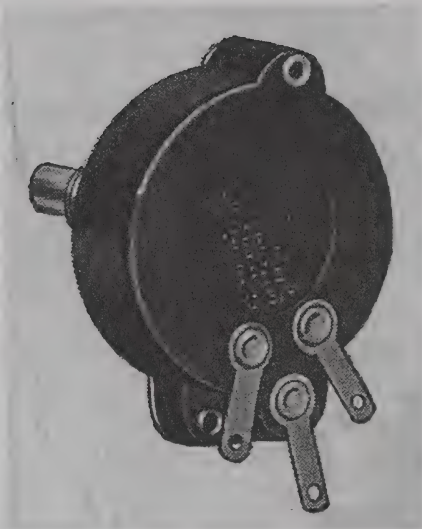


Fig. 46. Elf low power potentiometer. (Centralab Form 1001, Apr. 1932)

value or a "Service Pack" of Centralab selected values and quantities. Separately, this edition is the first to introduce a full line of more robust variable resistors for broadcast, recording, and sound projection purposes. Although previous *Volume Control Guide* editions offered piecemeal components, this marked the first consolidated presentation of commercial components. A variety of T-pads, T-pad faders, and L-pads were offered, generally in a housing 3½ inches diameter by 2 inches deep.[99] It appears that these early products were distinguished by a simpler white and blue packaging.

As early as the May 1932 edition of the *Volume Control Guide*, the type 310 resistor was derated to 0.2 W, and the type 314 (0.5W) and the odd type 315 (0.3 W) were introduced. Fixed resistor service packs containing one each of 500, 1k, 2k, 5k, 10k, 20k, 50k, 100k, 200k,

Table 5. Fixed resistor ratings summary. Part number 315 rated at 0.3 W was discontinued by November 1932. Part number 710 rated at 0.5 W is identical to the 310/510, except for having axial leads. Part numbers 510, 514, and 516 from 1938 are identical to the 300-series except for completely insulated end contacts.

P/N	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
310	0.3	0.2	0.3		0.5	0.5	0.5	0.5	0.5	0.5
314	---	0.5	0.75	1	1	1	1	1	1	1
316	1.5	1.5	1.5	2	1.5	1.5	1.5	1.5	1.5	2

and 500k ohm type 316 resistors and a reference wall chart were advertised. Alternately, boxes of ten resistors of a single value from 200 ohms to 5 megohms could be purchased. It should be noted that the abbreviation "M" was used to denote and identify kilohm resistors and the notation "MEG" denoted megohm resistors during this era. Examples of early and late 1930s fixed resistor packs and exemplary resistors are shown in Fig. 47, illustrating the continuing use of the motto "Permanent as Stone" for the fixed resistor product. In this edition, the Modu-pluG was morphed into the Modu-Potentiometer.[100] By November 1932, the physical appearance of the fixed resistors changed, and only the types 310, 314, and 316 were mentioned. The first ignition interference suppression resistors, to reduce electrical noise in the new auto radio applications, were introduced. Four different resistances were offered: 8k, 15k, 25k, and 50k ohms.[101] Virtual reprints of the May 1932 edition[102] were released in November 1932[103] and April 1933.[104] The contents are replicated except for pages 60–61, which listed special Centralab replacement controls. The special replacements were exact resistance duplicates to unique OEM parts. Each of the three similar *Volume Control Guides* contains differing listings.

Fig. 47. Resistor packs, ca. 1930 and 1937 with exemplary fixed resistors. (Author)

The impact of the depression produced visible changes in the *Volume Control Guide* as well as products and advertising. Most visible is the reduction in size and content of the 1934 edition, printed on acidic paper, and available at no charge. Significant was the discontinuation of the old Standard (or Senior)

2¼ diameter Radiohm and re-designation of the 1⅜ inch diameter unit as the "Standard." For the first time, a graph of the various available resistance tapers was published.[105] A separate booklet was issued for the new Series II Sound Projection Controls, which included T- Pads, T-Pad faders, L-Pads, straight line faders, and gain controls, all rated at 1 W and priced at $4.00–$15.00, as exemplified in Fig. 48. The Series II controls employed special graphite/carbon resistances and non-rubbing contacts for smooth constant impedance adjustment over their entire range. The entire assembly was encased in a steel shell for electrostatic and electromagnetic shielding as well as dust exclusion. It was claimed that cleaning was never required. In contrast, the Series I controls varied in design from simple carbon resistance (1 W), a combination of carbon and resistance wire (4 W), and resistance wire for all designs above 10 W.[106] The 1934 series of publications would be the last to use the Central Radio Laboratories name. Subsequent publications would use the Centralab identity exclusively, as a division of Globe-Union Manufacturing Co.[107]

During this period, a new development was brewing that was revealed in the 1935 *Volume Control Guide* (Fig. 49), which took on a new size and revealed a radial compression shoe and resistance element in the variable control products, as shown in Fig. 50, replacing the earlier axial compression arm design. As described, "More than 30 graduate engineers now guide Centralab products from start to finish."[108] Aside from the radio replacement part listing, the *Volume Control Guide* for 1936 did not introduce any significant new products.[109]

Through the early 1930s, the popularity of the ceramic fixed resistor design reportedly raised CRL to the number two position of fixed resistor suppliers out of a pool of six major competitors.[110] Given the frequent unpredictable wattage re-ratings for the fixed ceramic resistors, this statement is surprising.

On August 26, 1936, the parent company changed its name again, becoming

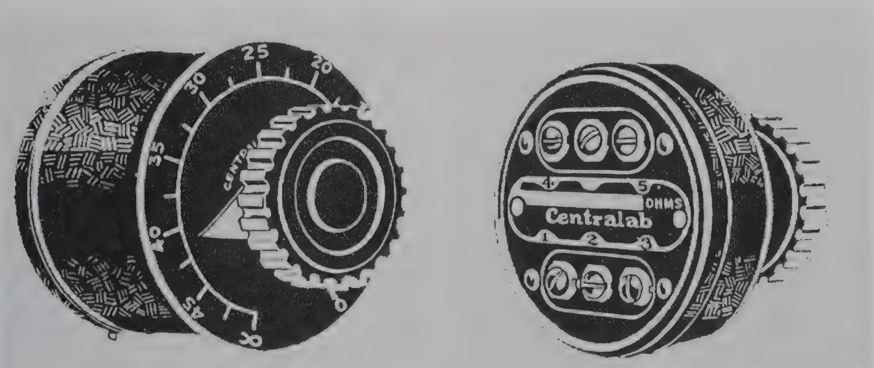


Fig. 48. Series II Projection Control L-Pad. (*New! Series II Centralab Sound Projection Controls*, Centralab Form 2009, Sept. 1934)

Globe-Union Inc., an identity it would maintain through the rest of its independent life. For reasons unknown, September 11, 1936, marked the day that unnamed holders of all 200 shares of Central Radio Laboratories voted unanimously to dissolve the company at a special meeting. This action was recorded by the Wisconsin secretary of state on September 19, 1936.[111] On this same date, articles of organization of Central Radio Laboratories, Inc., were filed with the secretary of state by George D. Spohn, Herman E. Friedrich, and Gerrit D. Foster for the manufacture and sale of radio, telegraph, and telephone parts and equipment. A total of 100 shares were allocated without par value, presumably held by Globe-Union, Inc.[112] Although Central Radio Laboratories, Inc., would remain the official business identity for the next 16 years, the 1935[113] and 1936[114] Centralab *Volume Control Guides* were attributed to Centralab, a Division of Globe-Union Mfg. Co.

It appears that during the mid-1930s, perhaps associated with the changes in corporate identity and new product designs, packaging was also changed. Gone were the 2½ × 2½ × 3 inch "cubes" that had been familiar since the CRL's founding. Boxes became elongated to accommodate extended shafts and smaller variable resistor bodies. The

Fig. 49. *Volume Control Guides*, 1935–1939. (Author)

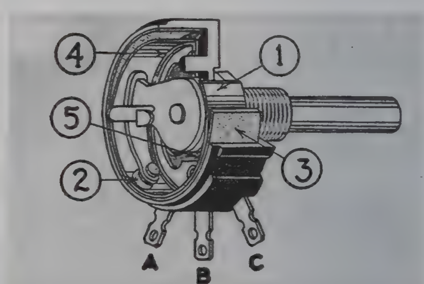


Fig. 50. Diagram of radial Radiohm showing: 1) rocking contact, 2) oiled wood bearing, 3) maximum resistance area for size, 4) riveted center contact lug, and 5) Bakelite constant tension washer. (*Volume Control Guide* 1935 edition, Centralab Form 1120, Mar. 1935)

color scheme also changed to a blue background with silver trim and white lettering. The patterning on the boxes included a small repeating diamond pattern, possibly in homage to the original CRL diamond.

With a new-found popularity in short wave listening and production of corresponding multi-band consumer receivers, the company saw another growth opportunity. In 1936, the waveband switch business of Perfex Corp. was acquired and added to the Centralab product line.[115] Bakelite wafer band switches first appeared in the Centralab *Volume Control Guide* for 1937 (Fig. 51),[116] and were additionally offered in a kit that allowed custom configuration. Also introduced in 1937 was the axial fixed ceramic resistor line, which was unchanged in construction from the prior product except for the lead configuration. A line of "Economy" PA controls, sized the same as the standard Radiohm, 1⅜ inch diameter, were introduced for "inexpensive sound equipment." It appears that this line was either short-lived or folded into the general Radiohm line, as it is absent in subsequent literature.[117] In addition to the standard *Volume Control Guide*, a small supplement to the 1937 edition provided an additional six pages of replacement listings plus the announcement of a new "Midget" Radiohm (1⅛ inch diameter base, 3⅜ inch shaft) for replacement use.[118] A new hinged universal shaft/adapter was also offered to accommodate either slotted or tongue type auto radio applications.

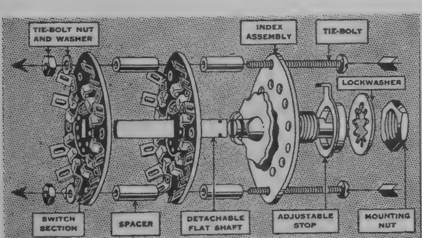


Fig. 51. Custom wafer band switch assembly kit. (*Volume Control Guide* 1937 edition, Centralab Form 1120, Feb. 1937)

After nearly five years of intensive research, the ceramic temperature compensating capacitor was introduced in 1938.[119] Capacities ranged from 5 to 350 pF for zero coefficient designs and 10 to 800 pF for negative coefficient models. Physically their sizes, in inches, ranged from ⅛ dia. x ⅜ long to ¼ dia. x 1¾ long. These new products featured a thin wall tubular ceramic that insulated the inner and outer capacitor plates (Fig. 52).[120] The metal plates were electroplated onto the ceramic insulator to preclude mechanical movement or warpage. Rated at 1000 VDC, these products could be made to exhibit either a zero coefficient

Fig. 52. Centralab thin wall tubular ceramic capacitor. (*Centralab* catalog No. 21, Centralab Form 1001A, Aug. 1939)

(Z-series, white body) or a negative temperature coefficient (N-series, green body), meaning that as a device warmed up, the thermal drift of a device was offset as the capacitor warmed. According to the *Volume Control Guide*, the maximum negative compensation produced was 0.00075 pF/pF/degC. All versions were rated at less than 10,000 pF. The RMA capacitor color coding scheme was utilized. Stabilization of radio frequency oscillators for superheterodyne receivers and transmitters was simplified significantly by this device.[121]

A single page devoted to company history and self-promotion was included in the 1938–1939 edition of the *Volume Control Guide*.[122] While comparable to the previous three editions, the switch line was expanded to include radio frequency (RF) Steatite/Isolantite ceramic insulated band switches intended for transmitter applications. An exemplary switch and box are shown in Fig. 53. The March 1938 issue of *QST* announced the availability of Isolantite switches for amateur use.[123] In addition, "Select-A-Switch" kits were announced that could offer up to 204,156 different Bakelite waveband switch configurations.[124] The Model 414 kit provided 98 varied Bakelite switch sections plus index assemblies, dial plates, and knobs. The Model 419 kit provided 68 Isolantite switch sections plus associated hardware. Both kits were priced at $100.[125] Separately, the number of replaceable shaft options for volume controls proliferated to accommodate the wide variety of replacement configurations needed to service both home and auto radio repairs.[126] Oddly, the breakthrough tubular temperature compensating ceramic capacitors appeared in the May 1938 *QST*, but did not make an appearance in any of the domestic pre-WWII *Volume Control Guides*.[127]

The 1939 supplementary edition of the *Volume Control Guide* marked the last of the pocket-sized (4 × 7 inch) editions.[128] At 78 pages, it was intended to

Fig. 53. Steatite high frequency band switch and box sides. (Author)

provide additional replacement information for later 1939 production models. Information for earlier sets was referenced back to the 1938–9 Master Edition. Curiously, one new product was announced, a lever action spring switch (Fig. 54) available in several different operating configurations, often found in audio and test equipment.[129] This design would prove to have a decades-long production history.

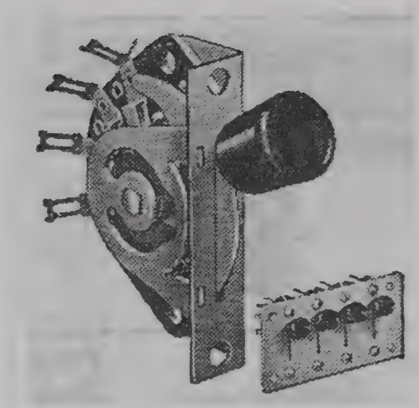


Fig. 54. Lever action spring switch. (*Volume Control Guide,* 1939 supplementary edition, Centralab Form 1120A, July 1939)

Epilog

The earliest legacy of Central Radio Laboratories was prematurely closed on March 15, 1938, portending the many unanticipated and disruptive changes Centralab and the country were soon to encounter. A small announcement in the next day's the *New York Times* appears to be the only mention of E. R. Stoekle's death at age 46 in Boston, following complications from eye surgery.[130] Stoekle left behind a legacy of over 50 U.S. and foreign patents related to electrical and electronic devices. His widow, Lillian, survived to age 82, passing in October 1972. At that time their estate was bequeathed to Northwestern University's Technical Institute.[131]

By the close of the 1930s, a 3-way division of the CRL markets was reported by Parsons:[132]

- 66 percent; OEM standard products: modified offerings for OEM designs (often mountings or shaft types);
- 22 percent; Replacement parts: offerings through approximately 500 jobbers in every state and Canadian province for small quantity sales to radio service shops, dealers, amateurs, and small industrial accounts;
- 12 percent; Export products: 29 countries in South America, Europe, Asia, Africa and Australia/New Zealand.

Centralab's business, as that of its parent, Globe-Union, had survived the Great Depression and appeared to be prospering. In addition to a number of lead-acid battery manufacturing plants across the United States, the Keefe Avenue plant was substantially expanded in both manufacturing floor and the addition of a four-story office building by the end of the 1930s to accommodate Centralab and Globe-Union battery businesses. After several different owners and nearly 100 years as a battery and electronics manufacturing plant, the facility was closed in 2019 and all remaining equipment and materials were removed. While the structure still stands at the time of this writing, its future is uncertain, destined

for repurposing or, more likely, a date with the wrecking ball.

In the growing shadow of World War II, old Centralab product lines would end and new technology developments needed for the war effort would set the stage for an unprecedented post-war era of electronic component development, manufacturing, and growth. That, however, is a story for another time.

Centralab would follow the trajectory of the U.S. electronics industry from the boom times of the 1950s through the withering of domestic consumer electronics in the 1960s and 1970s. Despite attempts to diversify product lines and develop alternative customer bases, Centralab's product and sales environment proved challenging. Following the acquisition of Centralab's parent, Globe-Union, Inc., by Johnson Controls, Inc., the Centralab Electronics Division was offered for sale within the year. In a press release dated March 27, 1980, Johnson Controls announced the sale of Centralab to North American Philips for $63 million. Initially maintained as an independent Philips division, it was combined into the BC Components division (BeyschlagCentralab Components) and ultimately divested to Vishay. CRL/ Centralab rotary and lever switches continue to be manufactured by Electro Switch Corporation. Current production models can be obtained from distributors such as Mouser Electronics. Both new and new old stock (NOS) parts can also be found online through eBay at a wide range of prices.

Author's Note

Dating of the various CRL and Centralab products and documents is challenging at best. Product names have been reused at various times and for various applications. Packaging is particularly challenging as illustrations of any kind do not seem to exist. To that end, this author would welcome any additional information, insights, or corrections from readers who may have had first-hand experience or information pertaining to early CRL/Centralab materials.

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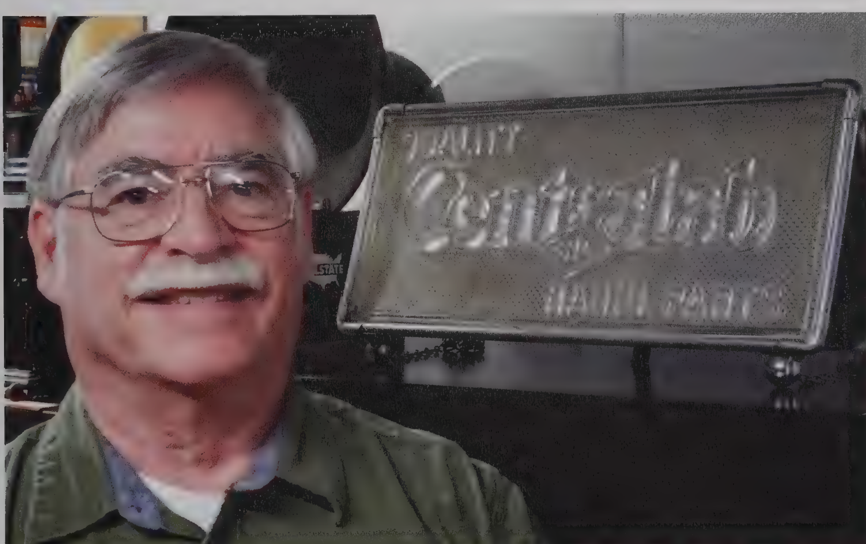
About the Author

Following completion of his post-graduate education and work as an environmental analytical chemist, **Glenn Trischan** chose to return to the Milwaukee area when offered a job in the Corporate Applied Research Group of Globe-Union. Although the Centralab Division was sold within the year following the acquisition of Globe-Union by Johnson Controls, Inc., Glenn directed materials projects cutting across the Johnson Controls product lines, including building controls, laboratory design and construction, advanced and automotive batteries, and automotive components. After over 30 years of service, Glenn retired as Manager of the Lithium-Ion Cell Development Laboratory at Johnson Controls.

Glenn's interest in radio, television, and electronics in general dates back to grade school, when the family's idled pre-war Zenith model Kenwood was rejuvenated and started receiving shortwave broadcasts. He is a native of the Milwaukee area with interests in both local history and radio collecting. Early during his employment, he learned of the Globe radio products. Quite casually he and his very patient wife, Edna, began to search antique stores and



Glenn Trischan

local flea markets in search of elusive examples. It was at one such flea market that a chance encounter with Bob Paquette opened the door to the world of radio clubs and radio swap meets. In radio collecting, one thing always leads to another, and soon there was an unexpected proliferation of Globe radios and artifacts along with other interesting radios and paraphernalia, which provide the basis for his works. His interest in further documenting the Globe and Central Radio Laboratories lines continues. He also collects wireless and battery-operated apparatus built in Wisconsin and Iowa.

Glenn is a founding member of the Wisconsin Antique Radio Club. In addition to AWA, he holds memberships in a variety of radio clubs around the country. He has previously authored an article on Lee De Forest and the American Wireless Telegraph Company, published in Volume 14 of the *AWA Review*, and also "The Radio Products of the Globe Electric Company," published in Volume 24. Glenn can be reached by email at gnets142@gmail.com.

Oliver Lodge's Contribution to the Invention of Radio

In the last fifty years, many historians, mostly British, have claimed that Oliver Lodge has precedence in the invention of radio based on his lecture to a meeting of the British Association for the Advancement of Science held in Oxford on August 14, 1894. Despite the fact that there is not a single document providing direct evidence to support these claims, they believed Lodge when he claimed many years later that he had sent and received telegraphic letters in Morse code at that meeting. In 2013, this author found irrefutable evidence to the contrary in the form of sworn testimony by Lodge given to an examiner for the British House of Commons on April 23, 1907, when Lodge admitted that he had not sent telegraphic messages or letters in 1894. After this evidence was published in the AWA Journal *in 2013, claims by English historians that Lodge sent telegraphic messages have been replaced with the lesser claims that Lodge "showed the potential" for electromagnetic waves to be used for wireless signaling, and that Guglielmo Marconi used an "improved version of his equipment" to send messages two years later in 1896. The purpose of this paper is to show that neither of these claims have any merit, and that Lodge's apparatus dating to 1894 could not transmit and receive telegraphic messages at any useful distance or at a practical word rate.*

PART I. A SHORT HISTORY OF LODGE'S CONTRIBUTIONS TO THE INVENTION OF RADIO

Guglielmo Marconi's reputation as the inventor of radiotelegraphy was secured at the turn of the century as a result of his transatlantic experiment on December 12, 1901, the date he claimed that he had received Hertzian wave signals at Signal Hill near St. John's, Newfoundland, which were transmitted from his station at Poldhu in Cornwall, England. Oliver Lodge was clearly unhappy with this turn of events because he believed that he had discovered and disclosed a method of transmitting and receiving Hertzian radiation in 1894 by using a Hertz oscillator as a transmitter and a Branly filing coherer circuit as a receiver. By all accounts, the French professor Édouard Branly was the first to discover that a tube of metal filings was a sensitive detector of electromagnetic radiation produced by a spark discharge at a distance of up to 20 meters in 1890.

After Lodge retired as principal at the University of Birmingham in 1919, he attempted to revive his reputation as the one who invented radiotelegraphy by making increasingly expansive and undocumented claims about his contributions to the development of radiotelegraphy in the 1890s.

During the last fifty years, many prominent historians, primarily British, declared that Oliver Lodge sent telegraphic letters or messages during his historic lecture that he gave to a gathering of the British Association for the Advancement of Science (BAAS) in Oxford, England, on August 14, 1894. This lecture was first given to the public at the Royal Institution on June 1, 1894, which was documented in several issues of the *Electrician* and later republished in a small book entitled *The Work of Hertz and Some of his Successors* in August 1894.[1] (This book is often referenced and will be referred to hereinafter as *The Work of Hertz.*) Because the lecture at Oxford was essentially identical to the lecture at the Royal Institution, Lodge documented his Oxford lecture with a short synopsis occupying little more than a half column in an issue of the *Electrical Engineer* dated August 24, 1894.[2] This paper, which made no mention of radiotelegraphy, went unnoticed by historians until 2013.[3]

It turns out that Lodge did not document transmitting telegraphic letters or messages to any distance during either lecture in 1894, nor did he even mention the subject of wireless telegraphy in any of his writings that year. Furthermore, in the two years that followed his Oxford lecture, Lodge did not show any interest in the subject of wireless telegraphy until September 21, 1896, when William Preece, Chief Engineer of the British General Post Office (GPO), revealed at a meeting of the British Association for the Advancement of Science (BAAS) held at Liverpool that Marconi had been experimenting with Hertzian telegraphy earlier that year and described some of his apparatus and test results.[4]

Despite the lack of documentation, a number of historians believed Lodge when he claimed in later life that he transmitted letters of the alphabet in Morse code during his Oxford lecture. The claims of eight prominent historians who believed Lodge demonstrated wireless telegraphy at Oxford are cited in the sidebar entitled "Authors Claiming Lodge Demonstrated Radiotelegraphy in 1894."[5] Lacking any documentation, how did it happen that so many prominent British authors claimed Lodge had sent telegraphic signals or messages in Morse code? Even stranger, some of these historians also asserted that Lodge had priority in the invention of radio as a result of the Oxford lecture, even though a basic tenet of according priority of invention was and still is documentary evidence or sworn testimony of observers that can be cross-examined, under oath if necessary. The story of how this came to pass is presented next.

Authors Claiming Lodge Demonstrated Radiotelegraphy in 1894

W. P. Jolly (1975): "A few letters were transmitted for the benefit of the audience. This was the first public demonstration of radio telegraphy, and Lodge gave it without any sort of fanfare."

Hugh Aiken (1976): "The signals had to cross the back yard of the [Clarendon] Laboratory and the front yard of the [Oxford] Museum, a distance of some 180 feet, and pass through two stone walls." "Did he demonstrate transmission and reception of Morse code? The answer would seem to be affirmative.... In this sense Lodge must be recognized as the inventor of radio telegraphy."

F. Pocock (1988): Pocock affirmed Lodge's statement from his autobiography: "It was easy to demonstrate the signaling of some letters of the alphabet, so they could be read by any telegraphist in the audience—some of whom may even now remember that they did so." "An audience which included professional scientists and engineers had been given a display of electromagnetic-wave telegraphy which confirmed the practicality of Trotter's and Crooke's proposals."

G. Basalla (1988):, "In 1894 Lodge…sent signals in Morse code across a distance of 180 feet and discussed the possibility of radio telegraphy."

Peter Rowlands (1990): "On 14 August, at the British Association meeting in Oxford, Lodge gave the world's first public demonstration of radio signaling in Morse code using electromagnetic waves."
"The transmitter was a Hertz vibrator activated by an induction coil, which was triggered by a Morse key, operated from another room, 180 feet away in another building…"

David Seeley (1994): "In 1894 Lodge made the first public demonstration of wireless telegraphy, of this scientific and historical fact there can be no doubt."

G.R.M. Garratt (1994): "Lodge was thus able to transmit dot and dash signals and so to demonstrate for the first time the possibility of sending messages by means of Hertzian waves." "Before the lecture, Lodge installed a Hertz oscillator and an induction coil having a key in the primary circuit in the Clarendon Laboratory, a distance of about 60 yards from the lecture theater.

Russell Burns (2004): "The transmitter, installed in the Clarendon Laboratory, comprised an induction coil, having a Morse key in the primary circuit, and a Hertzian radiator; the receiver in the lecture theater of the Oxford Museum 65.6 yards (60) meters away, consisted of his coherer, the marine galvanometer and a cell.... It is, therefore, unquestionable that on this occasion Lodge exhibited electric wave telegraphy over a short distance. It was the first demonstration anywhere of the principle of wireless telegraphy."

Lodge Invents the History of Inventing Radio

The history of the invention of radio as portrayed by Oliver Lodge and accepted by the historians listed in the sidebar is an invention itself. Oliver Lodge began to invent the history when he claimed for the first time, three years after the fact, that he had shown the same plan of signaling in 1894 as Marconi demonstrated in 1896 and 1897. Lodge made this claim in a letter he wrote to *The Times* (of London) dated June 17, 1897, immediately after Preece presented the results of Marconi's radiotelegraphic work at a Friday Evening Discourse delivered before the Royal Institution on June 4, 1897.[6] Specifically, Lodge wrote:

> "I myself showed what was essentially the same plan of signaling in 1894. My apparatus acted very vigorously across the college quadrangle, a distance of 60 yards, and I estimated that there would be some response up to a limit of half a mile.... My apparatus was substantially the same as that now used by Signor Marconi— there was a row of sparking spheres; ...."[7]

The apparatus for which Lodge claimed he showed "same plan of signaling" in 1894 as Marconi showed in 1897 was actually an experiment across the college quadrangle that he performed at the University of Liverpool. He sent a single pulse from a spherical radiator to a coherer circuit without a tapper apparatus, so it had no capability of distinguishing between long or short pulses of Morse code, much less messages like the ones Marconi sent in 1897. Lodge's source for his experiment, which he had described in his letter as "a row of sparking spheres," appeared in *The Work of Hertz* as "Fig. 19" (see Fig. 1). He described this experiment as follows:

> "When working with the radiating sphere at a distance of forty yards out of window, I could not for this reason shout to my assistant, to cause him to press the key of the coil and make a spark, but I showed him a duster instead, this being a silent signal which had no disturbing effect on the coherer or tube of filings. I mention 40 yards, because that was one of the first outdoor experiments; but I should think that something more like half a mile

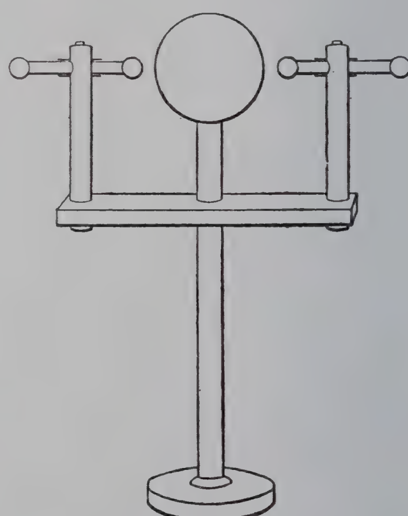


Fig. 1. Lodge used this spherical radiator consisting of three sparking spheres in 1894 for an experiment at the University of Liverpool where his coherer acted "very vigorously across the college quadrangle of 60 yards." (Lodge, *Work of Hertz*, 1894, p. 28)

was nearer the limit of sensitiveness. However, this is a rash statement not at present verified. At 40 or 60 yards the exciting spark could be distinctly heard, and it was interesting to watch the spot of light begin its long excursion and actually travel a distance of 2 in. or 3 in. before the sound arrived."[8]

Not only was Lodge's "plan of signaling" totally different from that of Marconi's plan, he was not the first one to excite a coherer with a sparking sphere. Branly had excited coherers with many different sources of Hertzian radiation in 1890 and 1891, one of which was a sparking sphere. Branly documented the use of a single spark discharge from a charged spherical radiator to excite his coherer circuit consisting of a tube of iron filings, a battery, and a galvanometer (see Fig. 2). While this configuration was not included in his seminal paper published in 1890, it was published in the French science magazine, *Cosmos,* in 1891, three years before Lodge's first lecture.[9] Lodge never referenced this article or the fact that Branly used a sparking sphere to excite a coherer with very short wavelengths long before he did.

Lodge's Equivocations

Lodge would continue to equivocate all his life by using the word "signaling" to mean either the detection of an individual electromagnetic pulse by a coherer, as he described in the above statement, or to mean the transmission and reception of letters or messages by Morse code, as he used in the same statement to describe Marconi's telegraphic apparatus. In the years that followed, Lodge also published many papers with equivocating statements that could be interpreted as a claim of making telegraphic demonstrations in 1894, but could also be interpreted as merely detecting signals without transmitting intelligence.

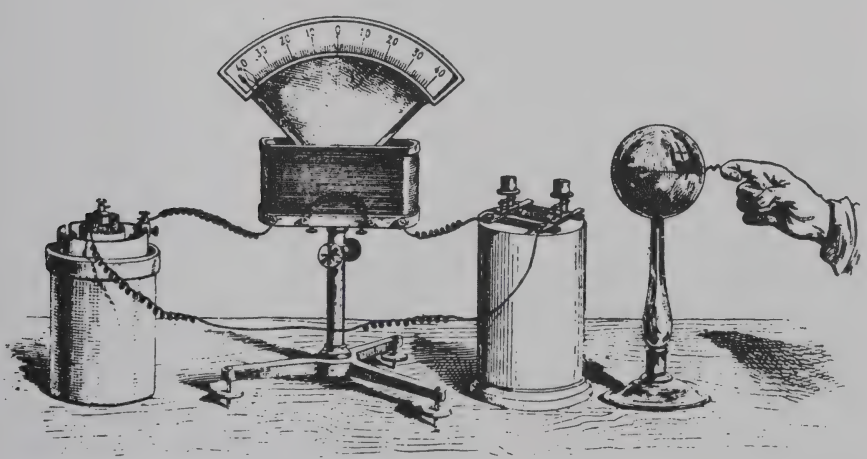


Fig. 2. Branly used a single spark discharge from a charged spherical radiator to excite his coherer circuit consisting of a tube of iron filings, a battery, and a galvanometer. (Kéramon, *Cosmos*, Vol. 18, 1891, p. 395)

An example of a carefully crafted, ambiguous statement that Lodge made can be found in a paper he published in 1898 entitled "Telegraphy by Electric Waves Across Space." Lodge wrote:

> "The 'coherer' is another and far more sensitive mode of detecting waves. It was observed by the lecturer in 1888, and in 1891 was applied by Branly to the detection of waves. With this arrangement waves can be detected several miles off, and can be made to work any telegraphic receiver. The principle was shown in Liverpool, London and Oxford in 1894."[10]

The last sentence with the phrase "principle was shown" was ambiguous because it could refer to "detection of waves" with a coherer, something other researchers had demonstrated before 1894, or "working with a telegraphic receiver," which no one had demonstrated before Marconi in 1896—and certainly not Lodge. The last sentence also implies that Lodge demonstrated waves could be detected several miles off with his apparatus—something that Lodge's did not do until long after 1897. The first person who demonstrated that a coherer would work with a telegraphic receiver—and to distances greater than a few hundred yards—was Marconi, who demonstrated transmitting and receiving messages to a distance of 14 km across the Bristol Channel on May 13, 1897—not just "several miles off."

Also, note that Lodge claimed he had first observed a coherer in 1888 and that Branly had observed a coherer three years later in 1891. Actually, Lodge first published a claim that he had observed what he later called a coherer in a two-page paper that was read as a contribution to the discussion of a paper read by Professor Minchin on November 23, 1893.[11] Lodge's claim was made only after he had read a draft of Professor Minchin's paper the day before it was read to the Physical Society. This paper opened by referring to Branly's work on "the effect [of electromagnetic radiation] produced on a glass tube filled with copper filings through the extremities of which tube are inserted two wires which dip into the filings."[12] Lodge did not provide any date for his claim of discovery in this extemporaneous paper, but in a footnote on page 21 of *The Work of Hertz* he stated that he had made this observation in an article he published on April 24, 1890.[13] Branly revealed for the first time that he had discovered a coherer consisting of a tube of filings in an article that he published on November 24, 1890. So, the earliest published claims of discoveries by the two pioneers were actually only seven months apart, not three years, as Lodge implied. Furthermore, the coherer that Lodge claimed he observed was a point contact coherer, which was never used in radiotelegraphy because it was unmanageable—something that even Lodge admitted. On the other hand, coherers consisting of tubes of metal filings that Branly discovered were used by virtually all wireless pioneers to detect Morse code signals using Hertzian waves in the 1890s.

The first person to make an unequivocal claim on behalf of Lodge that he

exhibited a system of telegraphy at both the Royal Institution and Oxford was an anonymous editor of the *Electrician*, who wrote:

> "Both at Oxford and at the Royal Institution, Dr. Lodge described and exhibited publically in operation a combination of sending and receiving apparatus constituting a system of telegraphy substantially the same as that now claimed in the patent we have referred to [Marconi's fundamental British patent 12,039 filed on June 2, 1896]."[14]

This article was deemed by most objective historians to be an overreach on the part of an editor who was trying to marginalize Marconi's work for nationalistic reasons. The photographs of Lodge's transmitter and receiver apparatus that accompanied the article (see Fig. 3) were completely different from the line drawings of Marconi's apparatus shown in his patent. Selected figures from his patent were published by the editor in an article that immediately preceded this one.[15] The image at the top of Fig. 3 represents a collection of the radiators that Lodge used in his lecture—none of which look anything like Marconi's tall monopole antennas that radiated long wavelengths or the Righi oscillator that he used as a spark source to excite the radiating monopole antenna.

The image at the bottom of Fig. 3 shows a number of Lodge's coherers, one of which was driven by a clockwork mechanism from a Morse inker,[16] making it clear that he used the Morse instrument for his tapper, not for observing or recording letters or words in Morse code, as Marconi did. Another faux pas was the editor's assertion that Lodge made telegraphic demonstrations at both the Royal Institution and Oxford in 1894. In a letter that Lodge wrote to John Ambrose Fleming dated August 24, 1937, he would later categorically deny

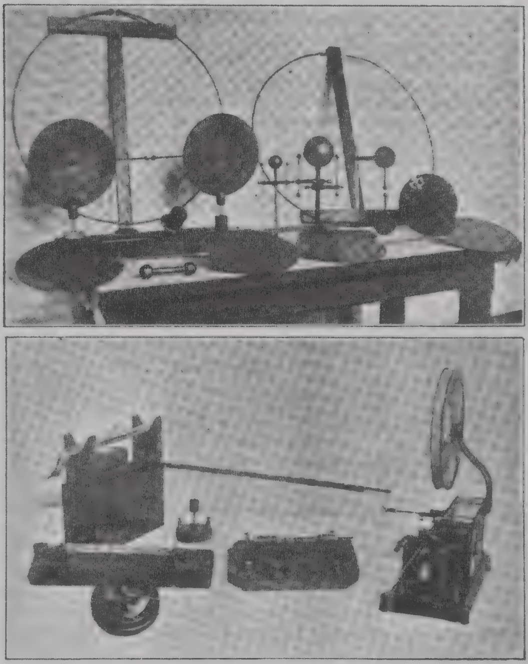


Fig. 3. The photographs of Lodge's transmitter and receiver apparatus dating to 1894 that accompanied an article in the *Electrician* did not look anything like Marconi's radiotelegraph apparatus of 1896, contrary to what the article claimed. (*Electrician*, Vol. 39, pp. 686–687)

making a telegraphic demonstration at the Royal Institution. Replying to Fleming's request for information on his telegraphic activities in 1894, Lodge wrote in part: "You are perfectly right that in 1894 at the Royal Institution I did not refer to telegraphy."[17]

Silvanus Thompson Becomes an Advocate for Lodge as the Inventor

Perhaps the first person of note to assert that Lodge sent telegraphic signals at Oxford was Silvanus Thompson, who wrote in 1898:

> "On several occasions, and notably at Oxford in 1894, he [Lodge] showed how such coherers could be used in transmitting telegraphic signals to a distance. He showed that they would work through solid walls. Lodge's greatest distance at that time had not exceeded some 100 or 150 yards. Communication was thus made between the University Museum and the adjacent building of the Clarendon Laboratory."[18]

There is no basis for Thompson's claim that Lodge sent signals to a distance of 100 to 150 yards during his Oxford lecture in 1894. In the paper Lodge wrote in August 1894 documenting his Oxford lecture, he never mentioned sending signals to 100 or 150 yards or "communicating" between the University Museum and the Clarendon Laboratory. Referring to his coherer as an instrument, Lodge stated: "In Liverpool a sphere nearly 70 yards distant had affected the instrument."[19] Surely, if he had sent signals to much longer distances in his Oxford lecture, he would have documented that accomplishment rather than referring to an experiment he had performed earlier at the University of Liverpool.

Thompson would continue to act as Lodge's surrogate by claiming that Lodge was the inventor of the wireless telegraph based on the telegraphic messages he sent at Oxford, while Lodge would continue to write equivocal claims about demonstrations of telegraphy. The most overt claims made by Thompson began shortly after Marconi succeeded in his transatlantic experiment on December 12, 1901. Thompson wrote a letter to the editor of the *Saturday Review*, published on April 4, 1902, in which he claimed Lodge was the inventor of wireless telegraphy:

> "Although Signor Marconi is not the inventor, but the skilled exploiter, of telegraphy without wires, everyone must admire the splendid success of his achievement in sending intelligible signals over fifteen hundred miles across the Atlantic. Of ultimate success in establishing regular wireless communication between the two continents there can be no question. The original inventor of the wireless telegraph, Professor Oliver Lodge, had supposed its limits of operation to be a few hundred yards.
>
> "It seems like the irony of fate that Professor Lodge, the well-known Principal of the University of Birmingham, after expounding the principles of wireless telegraphy in London and at Oxford in 1894, should find himself

pushed aside, first by the Italian [Marconi], who by dint of advertisement gains the public ear."[20]

There is no evidence that Lodge expounded the principles of wireless telegraphy in London, or at Oxford, or any time before Marconi came on the scene in 1896. Lodge denied the assertion that he had described telegraphic principles in London at the Royal Institution in his later exchange of letters with Fleming in 1937.

Thompson's letter provoked a number of letter exchanges with Marconi that were published in subsequent issues of the *Saturday Review*.[21] After an exchange of seven letters, Thompson sent an ill-advised letter to *The Times* that was published on July 15, 1902, which contained the following paragraph:

"'Professor Lodge's wireless telegram sent 200 yards compares poorly with Marconi's sent 2000 miles.' Granted. But that is not the point. The point is which of the two was first to send a wireless telegram? Was it Lodge in 1894 or Marconi in 1896? That which has apparently shocked Signor Marconi's supporters and roused some of them to fury is the discovery that Lodge actually did invent and exhibit wireless telegraphy by ethereal waves in 1894. What on Earth does distance have to do with the matter."[22]

Little did Thompson know that he would be hoisted on his own petard in 1907 when Lodge admitted that he did not send telegraphic messages or letters in 1894, or any time before Marconi did. Of course, that admission was not chronicled until 2013. Also, by stating that distance had nothing to do with the matter, he demonstrated his lack of knowledge about invention or the meaning of the word practical. Of course, distance had everything to do with invention when it came to wireless telegraphy by electricity during the period 1894–7.

Lodge Strives to Establish his Legacy after Retirement (1919–1931)

Lodge's publications with equivocal claims of his telegraphic demonstrations dating to 1894 abated for a number of years after Marconi's transatlantic experiment in 1901, and Marconi's reputation as the inventor of Hertzian telegraphy seems to have been secured. However, shortly after Lodge retired in 1919, he began a concerted effort to establish his legacy by giving lectures, writing articles, and publishing books in which he claimed many accomplishments—the discovery of electromagnetic waves independent of Hertz in 1888, the discovery of the coherer principle in 1889, and the first to transmit and receive telegraphic letters or words in Morse code in 1894. In some articles he claimed he sent telegraphic messages at both the Royal Institution in London and at the meeting of the British Association at Oxford, while at other times he claimed it was just at Oxford.

One of the earliest of these rash accounts Lodge gave later in life was delivered in a lecture to "a vast audience" in the Central Hall, Westminster, on December 13, 1923, which was organized

by *Wireless Review* and *Popular Wireless*, both well regarded British magazines for wireless telegraphy enthusiasts. Similar accounts of the lecture were published in both magazines. In the following account under the title "Practical Signaling," he claimed he sent telegraphic messages at both the Royal Institution in London and at the meeting of the British Association at Oxford:

> "Then, in 1894, I did exhibit signaling by this means both at the Royal Institution and the British Association, using a special galvanometer and having an automatic tapper for breaking the circuit and leaving it [the coherer] free to go on again. Thus we could get long and short deflections and Morse signals. What was now wanted was someone to take over this practical method and make it a practical system of signaling."[23]

Note his words "practical method." How could Lodge possibly have known in 1894 that Hertzian wave telegraphy using a coherer would eventually become a practical method, since he stated in his 1894 lecture at the Royal Institution that he believed the maximum distance a Hertzian signal could be detected by a coherer was a half mile? It was well known at the time that there was no practical application for wireless telegraphy at such a short distance. There were a number of editorials in electrical journals about the distances that were achievable by wireless electrical telegraphy versus the requirement or needs for wireless electrical telegraphy. One example of such an editorial appeared in the *Electrical Review* circa 1896, in which the conclusion was that the existing demonstrated distance of a few miles was insufficient for any application, and that there was a demonstrated need for communicating with offshore lightships:

> "Telegraphing without wires it has been shown can be practically accomplished to a distance of several miles, but this has hitherto only been done under conditions where there has been no necessity for such a system. How to apply this to the very different conditions of lightship and lighthouse communication remains to be shown, and if accomplished satisfactorily will certainly mark a new era in telegraphic progress."[24]

Also note that Lodge was trying to separate the concept of inventing radio from developing it into a practical system. It is one thing to verbalize the concept of using Hertzian radiation for transmitting and receiving intelligence, as William Crooks did in 1892,[25] and quite another matter altogether to invent and demonstrate a new and practical system for transmitting and receiving intelligence, which means to a practical distance and at practical word rates. That is the definition of invention.

In one of Lodge's most aggressive accounts of inventing radio, published in 1931, he clearly stated that he sent and received telegraphic messages in 1894:

> "In 1894 I showed that Hertz's waves, combined with a Branly detector, could

be used for sending and receiving messages in Morse code by the emission and detection of waves from an electric oscillator, a signal or series of waves, being emitted and detected at every spark."[26]

The most ambitious words Lodge wrote about inventing radio appeared in two of his books, *Advancing Science* published in 1931,[27] and *Past Years*, his autobiography published in 1932. An excerpt of the account appearing in his autobiography follows:

> "The possibility of actual signaling by the method was demonstrated during a lecture I gave to the British Association meeting at Oxford in August of that same year (1894).... When the Morse key at the sending end was held down, the rapid trembler of the coil maintained the wave production, and the detected spot of light at the receiving end remained in its deflected position so long as the key was down; but, when the key was only momentarily depressed, a short series of waves was emitted, and the spot of light then suffered a momentary deflection. These long and short signals obviously corresponded to the dashes and dots of Morse code; and thus it was easy to demonstrate the signaling of some letters of the alphabet, so they could be read by any telegraphist in the audience—some of whom may even now remember that they did so.
>
> "Truly it was a very infantile kind of radio-telegraphy; but we found that distance was comparatively immaterial; and at Liverpool, where I was then working, the dots and dashes were received with ease across the quadrangle, or from any reasonable distance."[28]

Lodge's statement that distance was "comparatively immaterial" has no meaning. Immaterial compared to what? Just because a signal is received with ease across the quadrangle of the University of Liverpool at 40 to 60 yards, or even at the half mile limit that Lodge stated in his 1894 lecture, it does not mean that it is received with ease at the shortest "reasonable distance." A reasonable distance in the context of invention means a useful or practical distance. The shortest useful distance for wireless telegraphy at the time was generally considered to be the distance from a shore station to a lightship at sea. William Preece at that time was attempting to extend the demonstrated range of his wireless apparatus using the inductive method of communicating intelligence from a few miles to a range satisfactory for lightships, most of them being located significantly more than a few miles from shore.

Historians Accept Marconi as the Inventor of Radio (1930s–1970s)

Lodge's attempts later in life to establish his place as the inventor of radio with his aggressive claims for priority in demonstration of radio communication were not immediately successful. Historians writing between the early 1930s and early 1970s generally conceded that Guglielmo Marconi was the inventor of radio—not Oliver Lodge. Examples of writings from this period by three

often-quoted historians support this contention. In 1936, author and historian Alvin F. Harlow wrote in his book *Old Wires and New Waves*:

> "Lodge admitted years afterwards that he 'did not realize that there would be a practical advantage in… telegraphy across space.'
>
> "At last came the practical man [Marconi]; not the pure scientist, but the inventor who thought of turning pure, abstract science to practical use."[29]

In 1944, radio authority Orrin Dunlap declared Marconi to be the inventor of radio in his popular book, *Radio's 100 Men of Science*: "Guglielmo Marconi, inventor of wireless, was born 'with a silver spoon in his mouth,' and his life is a story of the rich man's son who made good..." Dunlap declared Oliver Lodge was a "great physicist and thinker," but not the inventor of radio. Of Lodge, he wrote:

> "As the British asked with regard to Preece, so they inquired why Lodge was not the rightful inventor of wireless? Sir Oliver explained it this way: 'I was too busy with teaching work to take up telegraphic or any other development nor had I the insight to perceive what has turned out to be its extraordinary importance…'"[30]

In 1969, Charles Süsskind, engineer, author, and professor at UC Berkeley, was commissioned by the IEEE to research and write a series of articles entitled "The Early History of Electronics." Süsskind concluded that Lodge invented the circuits for fine-tuning, but with regard to the invention of radio he wrote:

> "Lodge, for all his brilliant popularizations, was a relative latecomer. Lodge's principal contribution to radiotelegraphy, a method of resonant tuning…would have been sufficient to ensure him a lasting place in the history of electronics; he need not have attempted to carve out a greater niche for himself."[31]

William Percy Jolly Disputes Marconi as Inventor of Radio (1974)

Beginning in the early 1970s, there was a considerable change in thought about Lodge's role in the invention of radio. One of the first respected historians to assert that Lodge had priority in the invention of radio during this period was William Percy Jolly, an electrical engineer and visiting professor of physics and electrical engineering at King's College, London. He wrote:

> "On 14 August 1894, at the British Association meeting in Oxford, Lodge transmitted electromagnetic waves from one room to another…. It was pointed out that these deflections could represent the dots and dash of Morse code, and a few letters were transmitted for the benefit of the audience."[32]

William Jolly claimed that Lodge had "demonstrated publically but incidentally that wireless telegraphy was possible…." Jolly also asserted that Lodge

took steps to commercialize wireless telegraphy by filing a patent on May 10, 1897, before any scientific description of Marconi's patent had been revealed:

> "But Lodge had already taken action even more positive than writing to *The Times*. On May 10, 1897 he [Lodge] filed his first wireless patent. The date is significant because it was before Marconi's first patent was published and before any scientific description of Marconi's apparatus had been allowed to appear."[33]

The argument that Lodge filed his patent on syntonic tuning on May 10, 1897—before the details of Marconi's patent were made public by Preece on June 1, 1897—implies that Lodge was aware of how to define a complete system of radiotelegraphy without any knowledge of Marconi's apparatus. This argument has a certain ring of truth, and the claim has been repeated at various times since then.[34] However, this argument is a red herring. The truth is that Preece disclosed a number of important technical details of Marconi's work at a meeting of the British Association in Liverpool on September 21, 1896, details that Lodge, who attended Preece's talk at the meeting, admitted he had heard. The following details were published two days later in the *Electrician*:[35]

1) "A young Italian, Signor Marconi, had described experiments in which he had, by means of Hertzian waves, transmitted signals over a considerable distance, and as a result Mr. Preece has assisted Signor Marconi to continue his experiments in London and on Salisbury Plain."

2) "Signor Marconi has now succeeded in producing electric waves and reflecting them from one parabolic mirror to another one and a-quarter mile distant, the waves falling on a receiving apparatus, which actuated a relay and produced Morse signals."

3) "The experiments have been made with crude apparatus and without employing 'any great amount of radiant energy.'"

4) "Signor Marconi must have made a radically new departure in the 'coherers' if the apparatus now enshrouded in mystery and hidden away on Salisbury Plain has been made *reliable*."

5) "So far 'coherers' have been almost too sensitive, and a trifle capricious in their behavior, and have required mechanical tapping to restore them to their high-resistance condition."

Lodge later made this statement about Preece's announcement:

> "When in 1896 Sir William Preece told the British Association meeting (as it happened in my laboratory) at Liverpool that an Italian gentleman (at that time unknown) was interesting the Post Office in a secret box, I knew practically what the box must contain, and immediately afterwards (the same day) I showed to a few friends a Morse

> tape instrument, very roughly, working on that plan."[36]

It is interesting to note that Alexander Popov read the same article in the *Electrician* and had a similar reaction. In the 1925 commemorative issue of *Electricity*, published in both Russian and French, Professor N. N. Georgievsky recalled Popov's reaction to reading this article: "This news reached Popov as well, and immediately roused him. Right at the exhibition, he told us that the transmission method invented by Marconi was probably no more than a repeat of his 1895 storm indicator."[37]

In December 1896, an editor of *English Mechanic and World of Science* revealed even more information about Marconi's system based on a lecture by Preece at Toynbee Hall on December 12, 1896:[38]

1) "Vibrations were simply set up by one apparatus and received by the other—the secret being that the receiver must respond to the same number of vibrations of the sender."

2) "The curious thing about it was that there was no new principle introduced."

3) "The first man who taught us how to generate these waves was Hertz, the German physicist, and they had been developed by others."

4) "Lord Kelvin it was who dubbed the apparatus first used for setting up these vibrations, 'the electric eye'.... He ventured to say that the subject was not only interesting in itself, but if the experiments were successful, as he believed they would be, it would be of inestimable value to our ships, for it would provide another way of communicating with lightships and lighthouses."

To say that Lodge filed his first patent on wireless telegraphy on May 10, 1897, without any technical knowledge of Marconi's system was obviously not true. Furthermore, what Lodge filed on May 10, 1897, was a preliminary patent application consisting of approximately two pages of text with no figures and virtually no technical information on a telegraphic system—just a general concept of syntony that mimicked what Lodge heard at the meeting of the British Association:

> "The method consists in utilizing certain processes and apparatus for the purpose of producing and detecting rapid electric oscillations, and in so arranging them that the excitation of a particular frequency of oscillation at the sending station may cause a Morse or any other telegraphic installation to respond at a distant station, by reason of being associated, through a relay or otherwise."

In this article, Preece had revealed the secret to Marconi's success: "the receiver must respond to the same number of vibrations." In plain English, that meant that the transmitter and receiver were tuned to the same frequency. It was not

until February 5, 1898, that Lodge filed a complete specification for his system of syntonized wireless telegraphy, by which time he had more than six months to study Marconi's published patent and to follow his work in the press.

Jolly must have believed that Lodge also had priority in the invention of wireless telegraphy because he wrote, "Many of Lodge's scientific friends were pleased about the award of the Rumford Medal because they thought this went some way to redress the injustice of the great public acclaim for wireless being given to Marconi when it belonged more properly to Lodge."[39]

Hugh Aitken Claims Lodge had Precedence in the Invention of Radio (1976)

Since Jolly's book was not widely distributed, it was left to Hugh Aitken to popularize the idea that Lodge had priority in the invention of radio when he published his award-winning book, *Syntony and Spark: The Origins of Radio*.[40] His book won the Dexter Prize awarded by the Society for the History of Technology as the best book published on the history of technology in 1976. Aitken did a substantial amount of original research and assembled a somewhat credible story on behalf of Lodge, although parts of his story could not be supported by documentary evidence and required faith that what Lodge claimed was, in fact, true. For example, both Lodge and many of his contemporaries claimed at various times that Lodge had demonstrated radiotelegraphy at both the Royal Institution and Oxford, and at other times only at Oxford. Recall that in 1935 Lodge contradicted his earlier claims by writing Fleming and explicitly stating: "You are perfectly right that in 1894 at the Royal Institution I did not refer to telegraphy."

Aitken believed that Lodge's demonstration of wireless telegraphy occurred at Oxford, but not earlier at the Royal Institution in London. He explained the difference in the two lectures by stating that Alexander Muirhead, a telegraph instrument manufacturer, alerted Lodge to the possibility of using Hertzian waves for radiotelegraphy immediately after attending Lodge's lecture at the Royal Institution:

> "Among the audience at Lodge's lecture to the Royal Institution in June 1894 had been a certain Dr. Alexander Muirhead, a fellow of the Royal Society like Lodge, but also and more significantly partner with his brother in a firm of telegraph instrument makers. Muirhead saw the commercial implications of Lodge's system immediately and lost no time in calling them to his attention. If indeed Lodge's Oxford lectures in the late summer of 1894 emphasized and demonstrated wireless telegraphy as his earlier public lectures had not, the explanation is to be found in Muirhead's intervention. The mirror galvanometer used in Oxford demonstrations was Muirhead's contribution—a sensitive instrument that his firm had made for use with the Atlantic cable; so was the siphon recorder; and so in all probability was the Morse key. These were telegraph instruments."[41]

Indeed, Lodge stated in a revision of *The Work of Hertz* with the new title, *Signaling through Space without Wires*, that Muirhead had foreseen the telegraphic importance of his work after the meeting at the Royal Society and had lent him a siphon recorder. Referring to himself in the third person, Lodge wrote:

> "In this non-perception of the practical uses of wireless telegraphy he [Lodge] undoubtedly erred. But others were not so blind, though equally busy; and notably Dr. Alexander Muirhead foresaw the telegraphic importance of this method of signaling immediately after hearing the author's lecture on June 1st, 1894, and arranged a siphon recorder for the purpose."[42]

However, there is no evidence a siphon recorder was used or even mentioned at the Oxford lecture and no evidence that Muirhead had foreseen the telegraphic importance of Lodge's lecture based on his attendance at the Royal Institution. According to all accounts, Muirhead lent Lodge a deadbeat mirror galvanometer to use at Oxford in place of the galvanometer he used at the Royal Institution. For example, it had been reported in the press that he had trouble with the wild swings of his galvanometer. Also, a writer for the *Electrician* stated that he had used the clockwork mechanism of a Morse instrument at the Oxford lecture to shake the filings,[43] and there is no evidence whatsoever that he used either a Morse printer or siphon recorder to record signals.

Unbeknownst to Aitken, Lodge had admitted earlier in 1907 that Muirhead did not mention any telegraphic applications to him until after 1894, and even then, Lodge stated he himself was not particularly interested. Lodge's statement to this effect will be reproduced in due course. It is my opinion that Lodge first claimed he had transmitted letters in Morse code at both the Royal Institution and Oxford, because the lectures were essentially identical. Later he realized that he could not claim that he sent long and short pulses at the Royal Institution because of the wild swings of his underdamped mirror galvanometer. While a single pulse produced by a spark source may have been short, the many swings of a spot of light on an underdamped galvanometer could last up to 12 seconds or more, depending on the sensitivity of the galvanometer.[44]

Nevertheless, Aitken concluded that Lodge must have been the inventor of radiotelegraphy:

> "Did Lodge in 1894 suggest in public that his equipment could be used for signaling? Did his lecture refer to the application of Hertzian waves to telegraphy? Did he demonstrate transmission and reception of Morse code? The answer would seem to be affirmative in each case. In this sense Lodge must be recognized as the inventor of radio telegraphy."[45]

Aitken's conclusion is troubling. The answer he gave—"would seem to be affirmative"—is tentative rather than definitive, as it must be for according priority of invention. Furthermore,

he provided no proof for the "affirmative answers" to these questions, other than accepting that statements made by Lodge himself were accurate. Thus, Aiken's conclusions depend completely on the veracity of Lodge's writings. Nevertheless, there is no doubt that *Syntony and Spark* changed the opinion of British historians, especially the historians listed in the first sidebar, who readily fell in line with Aitken's conclusion that Lodge had transmitted messages or telegraphic letters in Morse code at Oxford. Most of the accounts of Lodge's lectures by these historians can be traced directly to Aitken's book.

Sungook Hong Disputes Aiken's Version of Lodge's Priority of Invention (2001)

Aitken's opinion that Lodge invented radio was not seriously challenged until 2001, when it was vigorously disputed by Sungook Hong in his often quoted book, *Wireless: From Marconi's Black-Box to the Audion*, published in 2001.[46] Hong refuted each and every argument put forth by Aitken, and Hong's response was much more compelling than the arguments that Aitken's made, which relied heavily on Lodge's later unsubstantiated writings rather than contemporary documentary evidence.

For example, Aitken argued that Dr. Muirhead had mentioned telegraphic applications of Lodge's apparatus before his Oxford lecture, citing only Lodge's unsubstantiated claims. Hong refuted Aitken's argument by writing that it was only after the Oxford lecture that his wife inspired Alexander to think about wireless telegraphy.[47] Hong cited the noted British historian Rowland Pocock as his source.[48] Pocock wrote, "Muirhead, according to his wife's account, could not sleep on the night after the Oxford lecture and 'the next day he went to Lodge with the suggestion that the messages could be sent by the use of these waves to 'feed cables' [presumably marine cables].'" Pocock referenced a private publication written and published by Margaret Elizabeth Muirhead.[49]

Hong came to the following conclusion:

> "Marconi's "secret box" threatened the Maxwellian's hegemony in electrical theory and practice.... The British Maxwellians thought that they should not hand over an ether monopoly to Marconi, who they thought had violated the rules of the game. Marconi was not the inventor but only an "exploiter" of wireless telegraphy. It was these complicated contexts that led to the re-characterizing of Lodge's 1894 Oxford demonstration as the first demonstration of wireless telegraphy. His story has been retold many times since then."[50]

While Hong successfully argued that there was no evidence that Lodge transmitted letters or messages in Morse code at either the Royal Institution or at Oxford, he could not definitively prove that Lodge had not transmitted messages or letters. In short, Hong did not find a smoking gun. There the matter lay until 2013, when that smoking gun was found.

Discovery that Lodge Admitted he Did Not Transmit Radio Messages or Letters (2013)

In the summer of 2013, this author discovered two documents that had been overlooked or ignored by historians who had an interest in who had priority in the invention of radio. The first of these was the document introduced earlier entitled *Report of the Select Committee on Radiographic Convention*,[51] which was prepared for the British House of Commons to assist them in determining whether or not it was in the national and public interest to ratify the International Radio Telegraph Convention of Berlin: 1906.[52] The agreement document created at the convention had been signed by British representatives attending on November 3, 1906, but it had not yet been ratified by the British Parliament.

The Select Committee was charged with the responsibility of considering the contents of the signed document and reporting on "what, from the point of view of national and public interests, would in their opinion, be the effect of the adhesion or non-adhesion of this country to the Convention." To gather the necessary information, committee members invited experts from various disciplines to testify, including representatives from British wireless companies such as Marconi's Wireless Telegraph Company and Lodge-Muirhead Company. Oliver Lodge and Henry Muirhead, brother of Alexander, were asked to testify on April 23, 1907, and Guglielmo Marconi was asked to testify on April 30, 1907. All of the testimony was collected, recorded, and published in July 1907.

During Lodge's testimony, he was asked details about the telegraphic nature of his demonstration in 1894. Lodge's testimony is reproduced in the sidebar "Oliver Lodge Testimony," where the letter "Q" has been inserted for clarity before each question asked by the examiner for the committee, and the letter "A" has been inserted to indicate Lodge's response. As far as I am aware, this testimony and its relation to the controversy over whether or not Lodge demonstrated radiotelegraphy in 1894 or invented radio was chronicled for the first time in the *AWA Journal* published in 2013.[53]

The examiner began by asking Lodge where and when he first sent intelligible signals by means of Hertzian waves, and Lodge, after asking for a clarification, responded that he did not attempt to transmit by Morse code in his early experiments, and that all he did in his 1894 demonstration was to send short and long signals. By stating that he sent long and short signals, he was clearly referring to the Oxford demonstration—not the earlier demonstration at the Royal Institution in London. The examiner then asked if Lodge showed wireless telegraphy "potentially, but not actually," and Lodge responded "not actually—no." The examiner then asked if the idea of using Hertzian waves came to him after he had heard of Marconi, and Lodge responded that it came not to him, but rather to Dr. Muirhead. After the examiner asked for clarification, Lodge then said that it came to

Muirhead after the 1894 demonstration—not before. So, Lodge said that it was not his idea. If the idea of telegraphy by Hertzian waves was first conveyed to Lodge after his Oxford lecture, then he clearly did not refer to or demonstrate telegraphy at Oxford.

The conclusion that he did not make a telegraphic presentation at Oxford is supported by another unchronicled document written by Lodge himself in August of 1894,[54] in which he summarized his lecture at Oxford (see sidebar "Hertzian Waves"). This article, which had been overlooked by other historians, was discovered by this author in 2013.[55] It has been assumed by many historians that Lodge did not provide any documentation describing his Oxford lecture,[56] and with good reason. Lodge claimed as much when he wrote the following passage in a bibliography that he published in 1935 containing almost all of his previously published works:

> "Another pronouncement which had important practical consequences was my lecture on Ether Waves at Oxford in 1894, where the subject that has grown into wireless telegraph was first called attention to, but not reported upon. Had it not been that the Editor of the *Electrician* (who at the time was exceptionally competent) was present and made some reference to it, it might have escaped notice: though he was deceived by the title and some of the circumstances."[57]

Lodge's paper entitled "Hertzian Waves," with the byline "By Prof. Oliver Lodge," was located in a portion of the issue of the *Electrical Engineer* that described lectures given at the British Association meeting in Oxford. While

Oliver Lodge Testimony
April 23, 1907 (Ref. 14)

Q. Would you mind telling me what was the first date and place at which you transmitted intelligible messages by means of the Hertzian waves?
A. You mean by intelligible messages on the Morse Code?
Q. Practically—yes.
A. Which conveyed intelligence?
Q. Yes, more than a mere signal which could be construed to be "Yes" or "No."
A. In my early experiments, and in the demonstration of 1894,' I did not attempt to transmit words by Morse code; I used a Morse key and a mirror-signalling instrument, so that if I had been an expert telegraphist it would have been quite easy to send words, but all I did was to send short and long signals.
Q. That is to say, you claimed that you showed wireless telegraphy potentially but not actually.
A. That is so—not actually—no.
Q. But I gather from you that the idea of using Hertzian waves for practical telegraphic work did not occur to you until after you had heard of Marconi's achievement?
A. It occurred to Dr. Muirhead, who spoke to me about it, and who has his mind on telegraphy; but it did not especially interest me—not so specially.
Q. In fact it occurred to him, I understand you to say, after Marconi's?
A. No, after the 1894 demonstration.
Q. Before 1896?
A. Yes, in 1894 he was present at my lecture.
Q. But previous to 1896 you did not give the invention any personal application?
A. No.

this paper was written in the third person, it is obvious that Lodge prepared the paper, not only because of the byline, but also because of the opening line: "The author described...." Since there was no other paper written by Lodge covering his lecture, no editor could have made this statement. And Lodge often wrote in the third person.[58] Lodge's description of his Oxford lecture is reproduced verbatim here in the sidebar. There are three points to be made about the contents:

1) There is no mention of telegraphing.

2) There is no mention of long-distance transmission of signals from distant rooms. Instead, it states: "The coherer could detect the surgings in

Hertzian Waves
by Prof. Oliver Lodge

The author described some experiments to illustrate Clerk Maxwell's theory of light. He began by saying that his experiment referred to the waves generally known as Hertzian waves, though Maxwellian waves would be a more correct term. Various detectors of electric radiations were now known, but the most sensitive was one which depended on the breaking down of the resistance of a bad electrical contact when electric surgings passed across it. Such a bad contact could be made by a row of iron borings in a tube, or by a steel spring with its end resting on a metal plate. These instruments he called "coherers," from the fact that when exposed to electrical waves their resistance was diminished, the particles cohering together, as it were, so that when connected with a battery and galvanometer the latter showed an increased current. The original resistance could be restored on tapping. Using for radiator a sphere charged from an induction coil, he exhibited the phenomena of reflection, refraction, and polarisation of electric waves of about 9 in. in length. The coherer could detect the surgings in a sphere 5 ft. away when charged by an electrophorus, or the oscillations in an electric gas lighter; in Liverpool a sphere nearly 70 yards distant had affected the instrument. Polarisation was shown by gratings of parallel wires which stopped vibrations along the length of the wires and allowed those perpendicular to the length of the wires to pass undisturbed. One interesting experiment consisted in resolving a polarised beam into two beams polarized at right angles (elliptic polarization) by one of these gratings. Reflection from gilt paper and from a block of wood at the polarising angle were also exhibited. It was also shown that glass was transparent to these waves. The phenomenon of refraction was seen by the bending of a wave out of its course by means of a large prism of paraffin wax, but a lens intended to concentrate the rays to a focus was not so successful, although Dr. Lodge said the experiment had often succeeded in his own laboratory, and its failure was due only to the disadvantageous conditions under which he had to work. He subsequently showed that the coherer would not respond to long waves like those produced by the discharge of a Leyden jar, and that the change in its resistance was effected whether a current was passing through it at the time or not. Prof. Lodge then described an electrical theory of vision. He said the rod and cones of the eye were of such a diameter that light falling on them would excite transverse vibrations in them. It had occurred to him that such vibrations might increase the resistance of some part of the eye—perhaps the pigment cells—and thus the light stimulus would be recorded. Another stimulus would be necessary to correspond to the process of tapping which restores the coherer to its original state; this would be the sensation of darkness, and would be an actual positive sensation, not a mere absence of light. Between the stimulus of light and that of darkness there would be persistence of vision. Dr. Lodge showed an experiment to illustrate this, the coherer being restored by periodic tapping applied by a clockwork arrangement. For a continuous radiation on the coherer showed continuous indications, which died away when the radiation ceased.

a sphere 5 ft. away when charged by an electrophorus, or the oscillations of an electric lighter; in Liverpool a sphere nearly 70 yards distant had affected the instrument." This statement strongly indicates that no long-distance signaling occurred at Oxford—otherwise, the abstract would have referred to long-distance signaling at the Oxford lecture itself rather than earlier at the University of Liverpool.

3) The longer and shorter pulses—referred to later by Lodge as evidence of the "dots" and "dashes" of Morse code—were made in the context of demonstrating persistence of vision, not in the context of telegraphy.

A Revisionist History by Recent Lodge Historians (2020)

By coincidence, the year 2013 was also the year that a group of mostly British historians were funded by the Arts and Humanities Research Council in the UK to perform a multiyear study of the life of Oliver Lodge in a project entitled "Making Waves: Oliver Lodge and the Cultures of Science, 1875–1940."[59] This was a study of the work of Oliver Lodge, which included for example, "the many ways that signaling through space was understood in the period," and "Lodge's physics and engineering and the supposed differences between pure and applied science" (see sidebar "Making Waves: Oliver Lodge and the Cultures of Science, 1875–1940").

The study consisted of four workshops and two public lectures, and the end product was a book published in 2020, which was described as "the first scholarly book on Lodge to bring together the various aspects of his life and career."[60] The book entitled *A Pioneer of Connection: Recovering the Life and Work of Oliver Lodge* was edited by James Mussell and Graeme Gooday, who also contributed to the writing of two chapters. There were eleven other authors who wrote individual chapters

Making Waves: Oliver Lodge and the Cultures of Science, 1875–1940*

To understand a career such as Lodge's, it is necessary to take an interdisciplinary approach. The project is designed to bring together a range of scholars, archivists and museum professionals at four workshops, each focusing on a particular aspect of Lodge's career.

- The first will consider the place of science in the new Victorian universities;
- The second the many ways that signaling through space was understood in the period;
- The third Lodge's physics and engineering and the supposed differences between pure and applied science;
- The fourth scientific lives more generally, investigating different tools and methodological approaches for the study of historical scientific figures.

The project will maintain a blog, enabling conversation to continue between workshops and extend the network beyond the immediate participants; it will include a public demonstration of Victorian popular science, exploring the way in which scientific ideas were communicated in the past; lastly, it will publish an edited collection, producing the first scholarly book on Lodge to bring together the various aspects of his life and career.

*https://gtr.ukri.org/projects?ref=AH%2FK006223%2F2

covering various aspects of Lodge's life. The two editors and two of the eleven other authors had published historical works on Oliver Lodge and the Maxwellians: Peter Rolands, a recognized Lodge biographer and research fellow at the University of Liverpool where Lodge was a professor of physics and mathematics, and Bruce C. Hunt, a recognized Maxwellian biographer who is Associate Professor of History at the University of Texas at Austin, TX, where he teaches courses in the history of science and technology. It is also worth noting that Lodge's autobiography *Past Years*, published in 1931, was the main reference used for the study; it was cited no less than 50 times in the endnotes of *A Pioneer of Connection*.

It is surprising that there is no mention of Lodge claiming to have sent telegraphic messages in his 1894 Oxford lecture, as he later claimed in many documents—and especially in his autobiography. Also, there is no mention that Lodge admitted to the Select Committee on Radiographic Convention in 1907 that he had not sent telegraphic letters or messages in Morse code at Oxford, and that his admission was at odds with a number of recognized British historians in the last thirty years of the twentieth century, who claimed that Lodge had sent telegraphic messages or letters in Morse code at Oxford. In fact, there is no mention that any of the historians listed in the first sidebar claimed Lodge had sent telegraphic messages in 1894. All this factual history has been replaced in *A Pioneer of Connection* by vignettes that attempt to marginalize Marconi's work by statements that Marconi copied Lodge's apparatus or imply that Lodge indeed invented radiotelegraphy and Marconi merely extended it to more practical ranges:

> "Lodge published the lecture as *The Work of Hertz and Some of His Successors* later that year; however, stunned by Marconi's patent for a means of wireless telegraphy (and one that used an improved version of his apparatus)..."[61]
>
> "Both his Mann Lectures on lightning conductors in 1888 and those on the characteristic discharge of the traditional Leyden jar the following year established him as the leading interpreter of Maxwell's work and led directly to the lectures and demonstrations he gave in 1894 that, he later claimed, showed the potential for electromagnetic waves to be used for wireless signaling...."[62]
>
> "In his [Lodge's] account of the discovery of wireless, he credits Marconi with developing the commercial technology of wireless telegraphy based on Lodge's prior experimental researches...."[63]
>
> "All the same, Lodge was sure to register his contribution to the development of wireless in *Past Years*, stating clearly that he deemed the potential for his equipment to be used for signaling at the 1894 British Association Meeting (and so two years before Marconi appeared on the scene)."[64]
>
> "The view that Lodge had been 'trumped' by Marconi on the extended transmission of radio signals as a communicative medium, given Lodge's

claim that he had been first to succeed over a more limited distance, is part of the story that was apt to be retold in reviews of Lodge's life."[65]

These statements in no way reflect the true history of Lodge's claims for the invention of radiotelegraphy or Marconi's actual discoveries and inventions. The purpose of the remaining part of this paper is to clarify Lodge's contribution to the invention of radio by making the following points:

1) Lodge did not show the potential for wireless telegraphy at either the Royal Society in London or at the British Association meeting in Oxford,

2) Lodge's apparatus could not transmit intelligence to practical distances or at practical data rates to any distance, and therefore did not constitute invention,

3) Marconi did not copy any of Lodge's inventions, discoveries, or apparatus; it was Lodge who copied the work of others.

PART II. ANALYSIS OF LODGE'S CONTRIBUTIONS TO THE INVENTION OF RADIO

The first objective of Part II is to show that sending long and short pulses is a necessary but not sufficient condition to demonstrate the possibility of practical radiotelegraphy. It is axiomatic that communicating wireless messages in Morse code requires the transmission of long and short signals. Long and short signals have been sent and received in Morse code using electrical signals with audio, radio, and light frequencies long before 1894, so the fact that Lodge sent long and short signals in 1894 does not constitute evidence of invention.

The second objective is to show that Lodge's apparatus could not communicate intelligence at practical data rates to practical ranges because 1) the galvanometer he used was too slow to register the short and long pulses of Morse code, including appropriate spacings, and at practical data rates, and 2) the range was too short for any practical applications because Lodge focused on radiating short wavelengths with inadequate antennas that limited the range of his apparatus to impractical distances. Lodge never demonstrated that his apparatus using Hertzian radiation had a range anywhere as great as existing wireless apparatus of the day that used methods other than Hertzian radiation.

The third objective is to show that Lodge and his supporters who have claimed that Marconi copied Lodge's apparatus are in error. It was Lodge who actually copied the apparatus of Hertz and Branly that he used in his 1894 lectures. Lodge also copied Marconi's two tall antennas tuned to the same

frequency after Marconi's apparatus had been published in 1897, and he replaced his galvanometer with a Morse inker and a relay to decipher Morse code after he learned that Marconi had successfully used a Morse inker in a second circuit with a relay. These two components, first used by Marconi before Lodge used them in his patents filed in later 1897 and 1898, made all the difference between a practical radiotelegraph system and the apparatus that Lodge used in his 1894 lectures.

Before performing the analyses to support these three objectives, it is necessary to define the system that Lodge used in his 1894 lectures to send long and short signals that he claimed represented letters of Morse code. This is not straightforward because Lodge admitted in 1907 that he sent long and short signals in 1894, but not letters or messages in Morse code. The only experiment he presented at Oxford capable of receiving long and short signals was his vision experiment, which was the only experiment that featured an automated tapper. It was the automatic tapper that enabled his coherer and galvanometer to distinguish between a short pulse that represented a dot of Morse code, and multiple short pulses in rapid succession that represented a dash of Morse code. The problem with defining the vision experiment he used at Oxford is that Lodge did not define the source of excitation he used for his vision experiment, nor did he specify the distance between the source and the coherer circuit that he exposed.

Lodge's Apparatus for Sending Long and Short Signals in 1894

There is no mention of a telegraphic system in *The Work of Hertz* or in his summary of the Oxford lecture that was published in the *Electrician* immediately following his lecture. Lodge did not mention the subject of wireless telegraphy until after Marconi came on the scene in 1896. By all accounts, the only experiment he performed in 1894 that was capable of sending long and short pulses was his vision experiment. Lodge described the receiving circuit in the vision experiment as a Branly circuit with a series connection of a battery, a critically damped galvanometer, and a filing coherer that was tapped by a clockwork mechanism driven by a Morse inker. The tapping rate was one tap every tenth of a second, which he believed was the period for the persistence of vision of the eye. There was no mention of any antenna or collector of Hertzian radiation other than the Branly coherer circuit with a closed loop of wire connecting the components, which served as a collector of energy for the vision experiment.

The first time Lodge documented a diagram for a complete telegraph system, which he claimed he used in the early days (before Marconi appeared in England in 1896), was on February 5, 1898, when he filed a complete specification for his first wireless patent entitled "Improvements in Syntonized Telegraphy without Line Wires." The priority date for this UK Patent 11,575 was May 10, 1897, the date he filed his preliminary specification.

Lodge's Description of his Earliest Telegraph Apparatus

The earliest schematic diagram that Lodge documented for a complete wireless telegraph system appeared as "*Fig. 1*" in the complete specification for his patent application for UK Patent 11,575 (see Fig. 4).[66] He described this figure as "the simplest arrangement of an emitter and receiver heretofore in use."[67] By "heretofore in use" Lodge clearly meant that he had used it before, since there were no other wireless pioneers known to have used this particular configuration previously.

Lodge described the emitter reproduced in this figure as follows: "Electricity from a suitable source, such as a Ruhmkorff coil *a*, is supplied to a pair of conductors which discharge into each other from knobs *b* and *e* and thus excite oscillations which emit one or two waves before they are damped out."[68] This is clearly a Hertz oscillator, and Lodge identified it as such in the preliminary specification of this patent: "The ordinary Hertz vibrator and still more the radiating spheres which I have myself heretofore employed with a receiving coherer, are powerful radiators." The ordinary Hertz vibrator clearly refers to the vibrator Hertz used in his discovery of Hertzian radiation. The radiated wavelength of the ordinary Hertz vibrator was approximately 6 meters and the total length of the radiating dipole was approximately 3 meters.

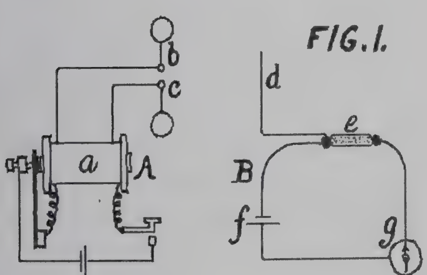


Fig. 4. Lodge identified this schematic diagram as the earliest wireless apparatus that he had used to transmit and receive signals representing letters in Morse code. (Complete specification for UK Patent 11,575 filed on February 1, 1898)

Lodge described the receiver in this figure as follows: "The receiving circuit consists essentially of a collector *d*, a coherer, *e*, a battery *f*, or other suitable source of electrical energy, and a telegraphic receiving instrument *g*, all in electrical connection as shown."[69] It is clear from the figure that the telegraphic receiving instrument was a galvanometer, one that he described later as being a critically damped Kelvin marine galvanometer. He described the coherer as follows: "As coherer I may use Branly's arrangement of a pair of conductors embedded in metallic grains or powder or filings, but I prefer selected iron filings of uniform size sealed up in a good vacuum and with the communicating surfaces or electrodes reduced to points or thin platinum wires fused into the glass and with their ends close together."[70] Lodge provided a line drawing of such a coherer in *The Work of Hertz* (see Fig. 5).[71]

While an automatic tapper is not shown in this figure, Lodge described the tapper that he used with the Branly coherer in his patent application as follows:

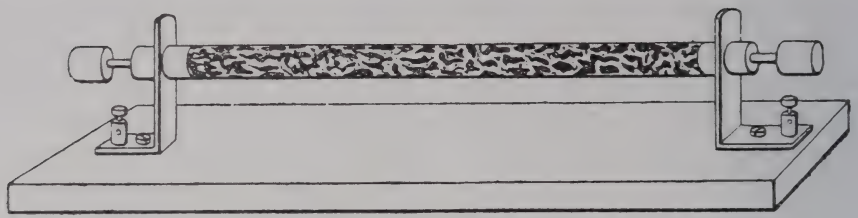


Fig. 5. In his UK Patent 11,575, Lodge claimed he preferred to have his coherer consist of "selected iron filings of uniform size sealed up in a good vacuum and with the communicating surfaces or electrodes reduced to points or thin platinum wires fused into the glass and with their ends close together." (*The Work of Hertz*, 1894, p. 23)

> "The original greater resistance of the light contact can be restored by a slight mechanical vibration or shock, which can be maintained automatically by any convenient means, such as the friction or percussion of clockwork, or electrical make and break, or any other shaking or trembling mechanism, as demonstrated by me before the British Association at Oxford in 1894 in a communication entitled 'an electric eye and a hypothesis concerning vision' (see the work of Hertz &c., page 27)."

This reference to "work of Hertz &c., page 27" is to *The Work of Hertz and Some of His Successors* published in 1894 before his Oxford lecture. This sentence unequivocally ties the schematic diagram in this patent application to Lodge's vision experiment at Oxford, and since *The Work of Hertz* book was published before his Oxford lecture, it means that the vision experiment at Oxford was essentially the same as his vision experiment at the Royal Institution. The only two exceptions, which are described later, were the use of a deadbeat galvanometer in lieu of an underdamped galvanometer, and the use of a clockwork tapper in lieu of an electric-driven bell tapper. A photograph of the "electrical make and break" tapper he referred to in *The Work of Hertz* is shown in Fig. 6,[72] but it was not used at Oxford. The "percussion of clockwork" tapper he used at Oxford was not shown in *The Work of Hertz*, but it was pictured in 1897 in the *Electrician* (see previous Fig. 3).

In 1923, Lodge made a line drawing of this tapper (see Fig. 7), which he then called a "decoherer," and he described it in some detail in *Harmsworth's Wireless Encyclopedia*.[73] Lodge was then acting as the Consultative Editor of this encyclopedia. This image confirms that the coherer rested on a stand so that it could be exposed directly to the source of Hertzian radiation—along with the interconnecting wiring loop in the vision experiment, which is not shown in this image.

Last but not least, Lodge identified the component in the schematic diagram labeled *d* as a "collector," which sounds suspiciously like an antenna, although he does not use that term. In Lodge's analog between the coherer and the human eye,

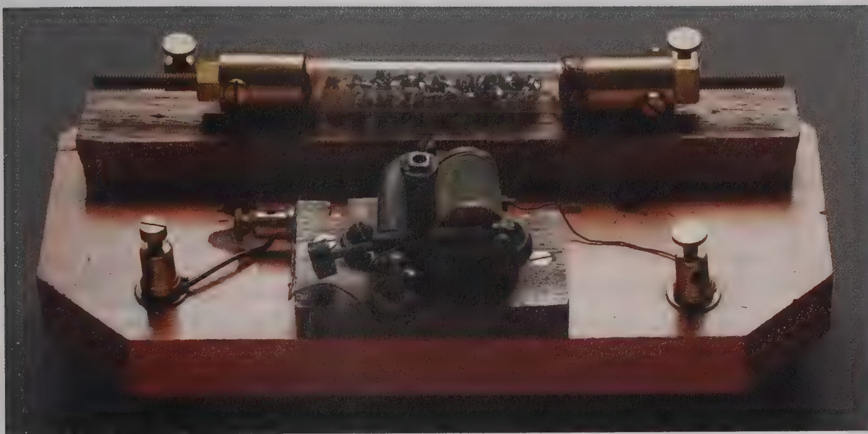


Fig. 6. Lodge discarded this electric-driven bell tapper that he used at the Royal Institution with a clockwork-driven coherer that was more suitable for his vision experiment at Oxford. (Science Museum Group Collection, iron borings coherer (Branly type), 1894)

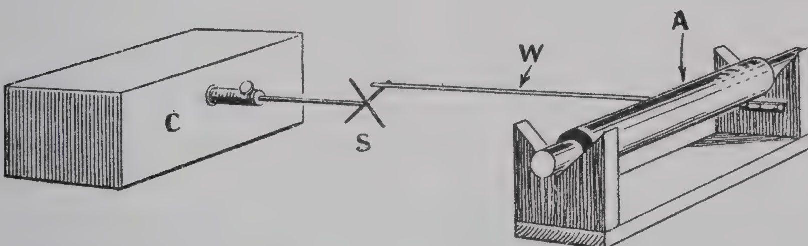


Fig. 7. Lodge prepared this line drawing of a clockwork tapper: The coherer "A" sat on a cradle, to which an insulating rod "W" was firmly affixed. The rod was tapped by a four-bladed spider wheel "S" that was rotated by a clockwork spring "C" of a Morse inker. (*Harmsworth's Wireless Encyclopedia*, Vol. 1, 1923, p. 655)

the coherer represented the cones and rods of the eye that collected the light, not a vertical rod. There is nothing that corresponds to a separate "collector" for the eye, and Lodge never claimed that he used a "collector" for Hertzian radiation in the form of a short wire in his vision experiment.

In Lodge's autobiography published in 1931, he described a slightly different system of telegraphy that he claimed he demonstrated at Oxford, but it did not mention an antenna for the receiver:

> "The possibility of actual signaling by this method was demonstrated by me during a lecture I gave to the British Association meeting at Oxford in August of that same year (1894). The tube of filing was provided with a tapping back arrangement, which restored them to sensitiveness directly [after ?]

> the wave had subsided.... The sending instrument was a Hertz vibrator actuated by an ordinary inducing coil set in action by a Morse key. The apparatus was in another room, and was worked by an assistant. The receiving apparatus was a filing coherer in a copper hat, in a circuit with a battery, actuating either a Morse recorder on a tape, or, for better demonstration to an audience, a Kelvin marine galvanometer, as first used for Atlantic telegraphy. This instrument was lent to me by Dr. Alexander Muirhead, whose firm habitually constructed a number of cable instruments....it responded to signals sharply, in a dead-beat manner, without confusing oscillations."[74]

It is clear from virtually all other accounts, including many by Lodge, that at Oxford he used a Kelvin galvanometer with a spot of light for detecting waves, and a Morse recorder for its clockwork mechanism to drive the tapper. Lodge's suggestion that he may have used a circuit with a battery to actuate a Morse recorder with a tape as his receiver is a fabrication. In the very next paragraph following the above quotation, Lodge writes: "When the Morse key at the sending end was held down...the *deflected spot of light* at the receiving end remained in its deflected position... [emphasis added]."

Aiken's Description of Lodge's Earliest Telegraphic Apparatus

Hugh Aitken also cited the above passage in *Syntony and Spark* to support his claim that Lodge had priority in the invention of radio. Referring to the above passage, Aitken claimed that Lodge had described all elements of a telegraph system:

> "All the elements of a telegraph system were here: exciter, Morse key, and receiver. We are not told what antennas are used, but if the apparatus were indeed the same as that used with the portable receiver on the previous June, the "dumb bell" oscillator used in the exciter and a short piece of wire attached to the detector would have been adequate."[75]

Aiken's statement that "all the elements of a telegraph system were here: exciter, Morse key, and receiver," was obviously not true because he added, "We are not told what antennas are used." It was a leap of epic proportion for Aiken to assert that "a short piece of wire attached to the detector" of a portable laboratory receiver apparatus "would have been adequate" as an "element of a telegraph system." The portable receiver to which Aitken referred was indeed presented to the audience at the Royal Institution lecture, but it was not intended to be a system of radiotelegraphy. It was also not important enough to be illustrated in *The Work of Hertz*. Instead, it was mentioned only in passing:

> "Also I exhibit a small complete detector made by my assistant, Mr. Davies, which is quite portable and easily set up. The essentials (battery, galvanometer, and coherer) are all in a copper cylinder three inches by two. A bit of wire a few inches long, pegged into

it, helps it to collect waves. It is just conceivable that at some distant date, say by dint of inserting gold wires or powder in the retina, we may be enabled to see waves which at present we are blind to."[76]

A photograph of this portable receiver was published later in *Signaling through Space without Wires* (see Fig. 8).[77] This portable receiver contained a coherer, a battery, and a speaking galvanometer; the concave screen displaying the spot of light reflected from the mirror within the galvanometer was mounted on the exterior. More to the point, there was no tapper to restore the coherer to sensitivity, so it could not distinguish between long and short pulses. The coherer was restored after each pulse of Hertzian radiation by a tap of the hand on the case. Also, a few inches of wire exposed at the rear was sufficient to detect Hertzian radiation at close range in a laboratory, but it was never intended to be used in a radiotelegraph system.

It turned out that the antennas on both the transmitter and receiver of all early radiotelegraph systems were critical components, as Marconi first demonstrated in 1896–7. It also turned out that the short piece of wire on Lodge's laboratory detector was only a few inches, which would have been quite inadequate for any practical radiotelegraphy system. Aitken was surely aware at the time he published his book that a wire antenna for a receiver was critical to a telegraph system. He also must have been aware that without asserting there was some type of antenna associated with the receiver he could not claim that Lodge had invented a practical system of radiotelegraphy. By associating the short

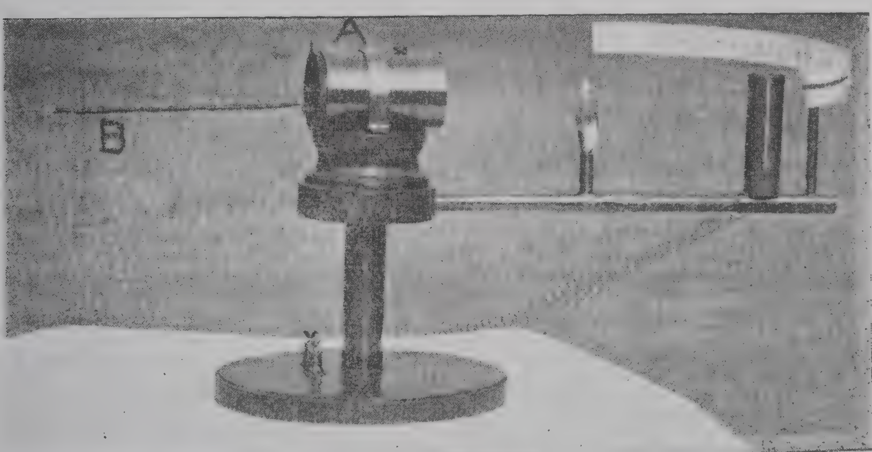


Fig. 8. Lodge's small portable laboratory electric wave detector consisted of a battery, galvanometer, and coherer situated within a copper cylinder enclosure with dimensions of three by two inches; to detect electromagnetic waves, a few inches of wire extending out of the case acted as an antenna to generate a small current that excited the coherer, which caused a larger current to flow through the galvanometer. (*Signaling through Space without Wires,* 1900, p. 33)

antenna from Lodge's laboratory apparatus with Lodge's coherer circuit using a tapper, Aitken was cleverly inferring that Lodge understood the importance of an antenna wire on a receiver for a telegraph system.

While readers of Aitken's book may have questioned his sleight of hand by migrating the antenna on a laboratory device to what he described as a complete telegraph system, who could argue with Aitken's assertion that Lodge invented the short antenna to receive Hertzian radiation used on the portable receiver he presented at the Royal Institution. After all, Lodge had described an experiment in *The Work of Hertz* where he demonstrated that a coherer within a well-shielded metal enclosure could be activated by a short piece of wire with one end attached to the coherer circuit and the other end extending out through a small hole in the enclosure wall where it was exposed to a Hertzian wave. Referring to a well-shielded box, Lodge wrote:

> "One thing in this connection is noticeable, and that is how little radiation gets either in or out of a small round hole. A narrow long chink in the receiver box lets in a lot; a round hole the size of a shilling lets in hardly any, unless indeed a bit of insulated wire protrudes through it like a collecting ear trumpet."[78]

Lodge also did not include an image of this experiment the 1894 edition of *The Work of Hertz,* but he did publish a line drawing of the experiment in *Signaling through Space without Wires,* at the same point where he described his portable detector (see Fig. 9).[79] What Aitken did not point out was that Lodge did not conceive of the experiment shown in this figure, so he did not conceive of the short antenna or the laboratory receiver. It was actually Branly who conceived of this experiment in 1890, and in the process he discovered and demonstrated that a short sense wire was a collector of sufficient Hertzian radiation to activate a coherer.

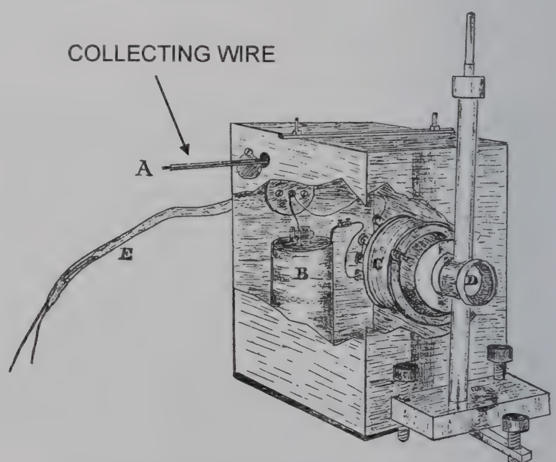


Fig. 9. Lodge demonstrated that a coherer placed within a well-shielded metal enclosure could be activated by a short piece of wire with one end attached to the coherer circuit and the other end extending out through a small hole in the enclosure wall where it was exposed to a Hertzian wave; this experiment formed the basis for the portable detector pictured in the previous figure. (*Signaling through Space without Wires,* 1900, p. 35)

Branly is First to Demonstrate a Receiver with a Short Wire Antenna

The experiment of the "receiver with a short wire" is one that Branly actually demonstrated and published four years before Lodge did in 1894. While Lodge claimed that he had discovered the coherer principle, he admitted only that Branly had discovered the filings coherer used in radiotelegraphy and that Branly was the first to demonstrate a coherer could be used to detect electromagnetic waves. However, Lodge never gave Branly any credit for the many experiments he performed with the coherer that appeared in his seminal paper published in *Comptes Rendus* on November 24, 1890, and especially not for the experiment of receiver with a short wire collector. Here is all that Lodge wrote in *The Work of Hertz* about Branly's experiments with coherers:

> "Nearly four years ago M. Edouard Branly found that a burnished coat of porphyrised copper spread on glass diminished its resistance enormously, from some millions to some hundreds of ohms when it was exposed to the neighbourhood, even the distant neighbourhood, of Leyden jar or coil sparks. He likewise found that a tube of metallic filings behaved similarly, but that this recovered its original resistance on shaking. Mr. Croft exhibited this fact recently at the Physical Society. M. Branly also made pastes and solid rods of filings, in Canada balsam and in sulphur, and found them likewise sensitive."[80]

A comparison of Branly's 1890–91 papers with Lodge's *The Work of Hertz* reveals that Branly published most of the experiments with coherers that Lodge published in 1894, and he presented most of the experimental results that Lodge claimed he had obtained between the end of 1893 and his first lecture at the Royal Institution in 1894. A comparison of the experiments and results obtained by Branly and Lodge has been published previously.[81] One of the experiments that Branly performed in 1890 was the experiment of the receiver with the antenna, which appeared in English in the *Electrician* in 1891 (see Fig. 10).[82] Compare Branly's experimental configuration with that of Lodge (see the previous Fig. 9). Branly described his experiment in the *Electrician* as follows:

> "Electric action gives rise to no alteration of resistance when the substance is entirely within a closed metal box. The sensitive substance, in circuit with

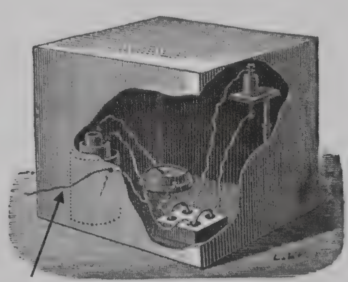


Fig. 10. Branly performed the same experiment in 1890 by exposing a wire, protruding from a shielded enclosure, to radiation that Lodge demonstrated four years later in 1894; compare this figure with Fig. 9. (*Electrician*, Vol. 27, 1891, p. 448)

a Daniell cell and a galvanometer, is placed inside a brass box [see Fig. 10]. The absence of current is ascertained, the circuit broken, and the box closed. A Wimshurst machine is then worked a little way off, and will be found to have had no effect. The same result will be obtained if the circuit is kept closed during the time the Wimshurst machine is in operation. If a wire connected at some point to the circuit is passed out through a hole in the box to a distance of 20 to 50 cm., the influence of the Wimshurst machine makes itself felt. On tapping the lid to restore resistance *the galvanometer needle remains deflected so long as the sparks continue to pass*...[emphasis added]. The movements of the galvanometer needle were rendered visible in these experiments by looking through a piece of wide mesh wire gauze with a telescope."[83]

It is ironic that Branly tapped the case shown in this figure periodically by hand to restore the coherer to sensitivity, thereby demonstrating that he could detect a train of Hertzian pulses. It is not out of the question that Lodge got the idea of automating Branly's manual tapping after reading the above paragraph from Branly's paper, which he admitted that he read well before his 1894 lectures. Lodge later claimed that this and many other experiments he presented in 1894 were new:

"I did exhibit at the Soiree of the Royal Society in June 1894, a compact Hertz receiver complete.... I took it up again after the death of Hertz, and after Branly had discovered the filings tube, and in 1894 showed many experiments, many of them new, which in a manner were dedicated to the memory of Hertz."[84]

This vignette is a cautionary tale to point out that most of what Lodge presented in his 1894 lectures having to do with coherers as detectors of electromagnetic radiation—not just this experiment—had been published by Branly well before 1894. Branly actually performed a number of additional experiments that were published in numerous papers prior to 1894.[85] One example is Branly's configuration, shown previously in Fig. 2, where he excited his coherer circuit by discharging a nearby sphere. Lodge often mentioned that he was able to generate very short wavelengths to excite his coherer experiments by the discharge of a single small sphere with a diameter of 5 or 6 inches, but he never mentioned that Branly had published that experiment with the coherer years before he did.

Lodge's Configuration Used for the Analysis

For purposes of the analysis that follows, Lodge's schematic diagram from his patent application (Fig. 4) will be used, but without the short vertical collecting wire. Lodge certainly understood the importance of an antenna in the receiver circuit of Marconi's apparatus at the time he prepared this image, and he clearly added the wire *d* to "*Fig. 1*" of his schematic, which he had never

mentioned previously. However, there is no evidence that Lodge used a vertical wire antenna with the receiver for his vision experiment, the only experiment he described in which he used an automatic tapper, which was necessary to create a long signal from a number of closely spaced short pulses produced by his Hertz oscillator.

Even if Lodge had used a short wire antenna in 1894, he could not possibly have determined or demonstrated the importance of two large antennas in the confines of a laboratory at his university or a lecture room at Oxford. It will be shown in due course that a short single wire antenna attached to the coherer circuit, as shown in his figure, would not have made any difference in the range of Lodge's telegraph system.

Long and Short Pulses Do Not Show the Possibility of Actual Signaling

Lodge admitted in 1907 that he did not send letters or messages in Morse code, but he did claim that he sent and received long and short signals that showed the possibility of actual signaling with Hertzian waves. In the context of invention, "actual signaling" means a system that could transmit telegraphic messages to practical distances at practical data rates. It does not and cannot mean a demonstration of the *principles* of radiotelegraphy with an apparatus that cannot and could not ever send messages to practical distances, or practical data rates at any distance.

If practical ranges do not matter in the context of invention, then Heinrich Hertz must be declared the inventor of radiotelegraphy with the apparatus he used in 1888, which is pictured schematically in Fig. 11.[86] He invented the Hertz oscillator with a dipole radiator driven by a Ruhmkorff coil, which was capable of transmitting Hertzian radiation in excess of 100 pulses per second. This pulse rate was sufficient to send Morse code signals and messages at a word rate of over 20 words per minute, even in the presence of noise, by turning on and off the switch between the battery and the primary winding of the coil to form long and short pulses with appropriate spaces between. He also invented the Hertz resonant loop detector capable of detecting Hertzian radiation at a distance of up to 20 yards, which was in the far field of the dipole radiator and therefore constituted reception of Hertzian waves. His resonant loop detector spark gap was self-restoring, and he stated that the loop could detect individual signals as fast as his Ruhmkorff coil could generate

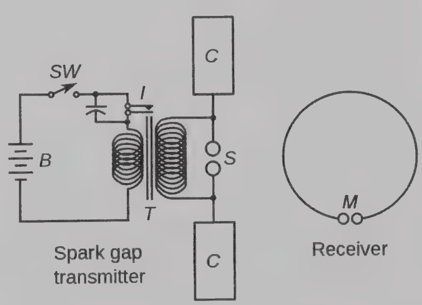


Fig. 11. Hertz's dipole oscillator radiator driven by a Ruhmkorff coil was capable of transmitting Hertzian radiation with messages in Morse code at high word rates, and his resonant loop detector had a demonstrated capability of receiving data up to a distance of 20 meters at equally high data rates. (Hertz_transmitter_and_receiver_-_English.svg)

them.[87] In fact, at medium spark rates of, say 100 pps, his spark detector would have produced a modulated musical tone that could have easily been read by any telegrapher of the day.

There are two objections to saying that he invented radiotelegraphy. The first is that he did not consider using Hertzian waves for telegraphy at the time, but then neither did Lodge. The second objection is the limit on the maximum distance he could detect sparks with his resonant loop detector, which was 20 yards in 1888. While he could have achieved longer distances with higher radiated power, it is conceded by all that the practical range of his apparatus, even with a larger dipole radiator would have been less than half a mile—the same range that Lodge stated. Lodge demonstrated a maximum distance of 40 to 60 yards in 1894, and projected that the maximum distance of his apparatus was a half-mile. In terms of the practicality of the two apparatuses with regard to demonstrated range, there was little difference.

The cynic might say that it was only a few years later that Marconi showed the distance of Lodge's apparatus could be extended to a practical range, whereas no one has ever shown that the range of Hertz's apparatus could be extended to a practical range. The cynic would be wrong. Marconi demonstrated that *his* apparatus could be extended to long ranges with practical data rates, but it was not by using *Lodge's* apparatus or just by increasing the radiated power, as many claimed.

It will be shown that Marconi achieved longer ranges because he used much longer antennas on both his transmitter and receiver, which were very different from the one small dipole radiator that Lodge used as his source. Lodge had no antenna on his receiver. It will also be shown in due course that Lodge's apparatus could not be extended to practical ranges, even with a much longer dipole radiator or two short dipole radiators. Equally large antennas for the transmitter and receiver were absolutely necessary for transmitting messages to practical distances with Hertzian radiation at that time. The fact is that no one has ever shown the range of Lodge's 1894 apparatus could have been extended much beyond a half-mile—not even Lodge himself.

Lodge's Galvanometer was the Achilles Heel for Practical Word Rates

The Achilles heel in Lodge's receiver for practical word rates was the Kelvin galvanometer that Lodge used in his Oxford lecture, because it was too slow for practical wireless telegraphic applications. This point has escaped many historians, particularly those who believed that Lodge demonstrated the possibility of telegraphic communication by sending and receiving long and short signals with telegraphic devices. Many historians lauded Lodge's use of a deadbeat galvanometer because it responded without wild oscillations and because it consisted of telegraphic equipment that was used on submarine cables to allow interpretation of Morse code messages. Few if any wireless telegraphy historians have mentioned the fact that the Kelvin

galvanometer used on submarine cables was not designed to detect and decipher long and short pulses in rapid succession.

It turns out that it was necessary to send positive and negative signals of the same duration on marine cables rather than long and short signals. This technique reduced the dispersion in the Morse code signals as they propagated from the source at the transmitting end to the receiver at the destination. An example of the positive and negative signals transmitted and received on a marine cable is shown in Fig. 12.[88] The spaces between letters and words used in Morse code on landlines were retained, but the pulses representing dashes and dots of Morse code were all of equal length. This scheme worked as long as the pulse width of the plus and minus signals, representing dots or dashes, were no longer than the length of the shortest spacing between the plus and minus signals.

The use of positive and negative signals of the same duration in lieu of long and short signals also increased the word rate, since the dashes of Morse code required three dot spaces of time, whereas the dashes used on marine cables used only one dot space of time. The use of positive and negative signals did not completely eliminate the distortion, an example of which is shown in the lower portion of this figure that was recorded on a siphon recorder at the opposite end of the cable. However, with the positive/negative polarity scheme and the siphon recorder, it was possible to send messages at reasonably high data rates, and it soon replaced the Kelvin galvanometer used on submarine cable receiving stations.

Quantifying the Kelvin Galvanometer Response

The Kelvin galvanometer used on the submarine cables with positive and negative pulses of the same length for both the dots and dashes worked because the galvanometer indicator was able to return to zero after each pulse representing a dot or a dash, thereby establishing a baseline for the next pulse. The time for the swing of the indicator of a galvanometer from zero to its maximum, either positive or negative, was approximately equal to the relaxation of the swing from its

Fig. 12. An example of the positive and negative signals transmitted and received on a marine cable in Morse code, where the spaces between letters and words are retained but the lengths of the dashes and dots are all identical; there are no long or short pulses. (*Submarine Telegraphy*, Western Union Tel. Co., 1920, p. 90)

maximum back to the zero baseline after the pulse ended. This scheme of using the same pulse length for dots and dashes did not work for wireless telegraphy because the battery in the coherer circuit had a fixed polarity, so the direction of the galvanometer swing was not affected by the polarity of the received signal.

Since there were sixty dot spaces to a standard word of Morse code, at one word per minute each dot space occupied one second. So, if the one-way throw time of a galvanometer needle was greater than one second, which it was, the needle could not return to the baseline before an excursion began for the next character. Thus, the resulting distinguishable word rate could not be much greater than the minimum one-way swing time of the galvanometer. As a rule of thumb, a one-way galvanometer indicator swing time of one second will limit the recognizable word rate to about one word per minute. This can be illustrated by plotting the needle position of a galvanometer with a swing time of one second (between 0 and the full scale position) as a function of time for a single letter of Morse code at a rate of one and two words a minute.

For example, assume a voltage or current is applied to a galvanometer to represent the letter "c" in Morse code (– · – ·). If the sending rate is one word per minute by long and short electrical pulses, the dots will consist of one second pulses, the dashes will consist of three second pulses, and the dot spaces between the dots and dashes will also be one second. To simplify this example, it will be assumed that the swing time up and down the scale is linear with time, an approximation that results in a relatively minor error. It will also be assumed that the current pulses are adjusted to raise the needle to the maximum position on the scale, and the galvanometer has a swing time up of one second (zero to maximum) and a fall time down of one second (maximum to zero).

The position of the needle with respect to time is plotted in Fig. 13 for two different assumed word rates: 1 word per minute on the left and 2 words per minute on the right. The vertical scales represent the relative position of the needle between zero and the maximum position of the scale, which is designated on the scale as one unit of current or voltage. The horizontal scales represent time in seconds. The lengths of the dots and dashes are represented by the solid lines at the top of the scale, where the length of the dash is three times the length of the dots. The spaces between the characters in the letter are equal to one dot space.

For the case on the left, the word rate is one word per minute and the swing time up or down is one second—a movement rate of 10 vertical current divisions in one horizontal time division. Beginning with the long dash of three seconds, the needle will swing to the full scale (10 vertical divisions of needle position) in one second (one horizontal division of time) and remain there for two seconds—at which time the current representing the first dash ends. The needle then drops to zero in the one dot space (one division of time), just as the current from the first dot sends the needle back up to full scale in one second (one division of time). It is evident that the

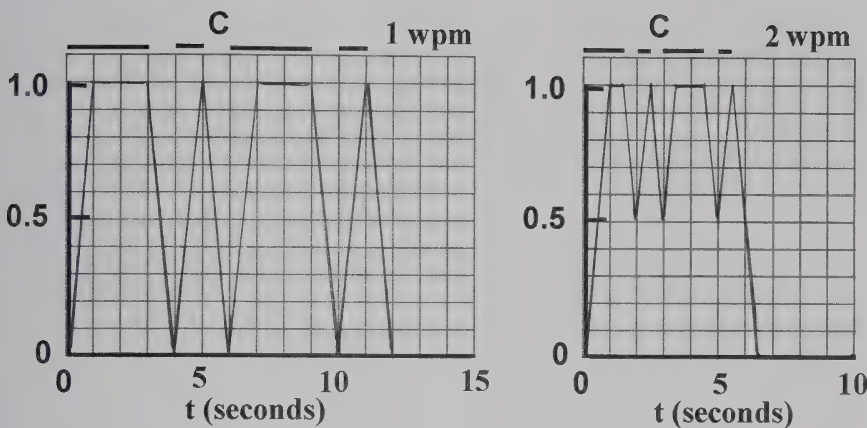


Fig. 13. The position of the needle with respect to time is plotted for two different assumed word rates: 1 word per minute on the left and 2 words per minute on the right. The vertical scales are the relative position of the needle between zero and the maximum position of the scale, and the horizontal scales are time in seconds. The lengths of the dots and dashes are represented by the solid lines at the top of the scale. (Author)

needle returns to the baseline after each character (dot or dash) in the letter "c" at one word per minute, and the dots and dashes in the letter "c" can be easily interpreted. According to the time base, the total time to transmit a "c" at one word per minute is 12 seconds. However, the speed of one word per minute is far too slow for practical radiotelegraphy, and the swing time of a galvanometer of one second is faster than that for actual galvanometers of the day in 1894.

When the word rate increases to only 2 words per minute, as it does in the needle movement representation on the right, the letter "c" does not look anything like the representation on the left. In this case, the time scale on the horizontal axis remains the same, but the dot and dot spaces decrease from 1 second to 0.5 seconds, and the dash lengths decrease from 3 to 1.5 seconds, as indicated by the horizontal lines at the top of the scale. For the first dash, the needle still moves to full scale in one second, but remains there for only one second instead of two, as in the first case. However, the dot space that follows is only a half second, and the needle can fall only to the half-scale point in the half second before the signal for the next dot sends it back up to the full scale position. It is clear that the needle does not return to the baseline after each dot or dash; the needle appears to oscillate in the upper portion of the scale, and the time scale for the reception (and for recognition) of the letter is compressed by a factor of two. The problem of interpreting the needle swings only gets worse for the minimum practical word rates, which were determined by convention at a later date to be 10 words per minute for commercial work.

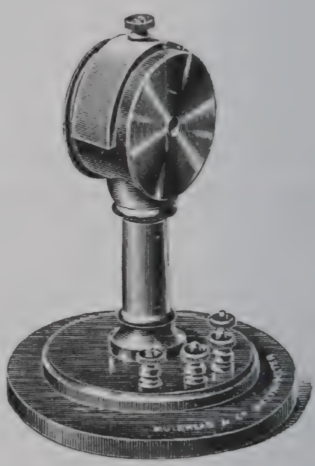
The parameters in this example are hypothetical, chosen by this author to demonstrate the problem of using a galvanometer to interpret Morse code signals at practical data rates in Hertzian telegraphy. The same analyses and needle position plots are presented for a whole word of Morse code using the best performing galvanometer (with the fastest swing time) that may have been available to Lodge in 1894.

Galvanometer Parameters of the Day

Lodge stated that the galvanometer he used was a Kelvin deadbeat speaking galvanometer lent to him by Alexander Muirhead, a manufacturer of telegraphic equipment, which strongly suggests that it was manufactured by the Muirhead Company. The most important unknown parameter by far is the swing time of the galvanometer needle, both up and down, something that Lodge never revealed for his deadbeat galvanometer. Also of interest is: 1) the degree of non-linearity of the needle position on the scale during the swing and the degree of error by assuming a linear swing to simplify the analysis, and 2) whether or not the swing time can be minimized by limiting the maximum swing to a level lower than the maximum on the scale (by using a shunt resistor across the galvanometer).

According to galvanometer catalogs and articles of the day, Kelvin galvanometers from this period had one-way swing times as low as three seconds and as high as 20 seconds. It was not until the twentieth century that galvanometers with swing times of less than 2 seconds were reported, and they were generally found on D'Arsonval galvanometers.[89] There were a number of Kelvin galvanometers listed in a Muirhead Company catalog published in 1893—one of which that may have been used by Lodge is reproduced in Fig. 14.[90] The external concave mirror for this speaking galvanometer was sold separately. Unfortunately, there is no swing time or period listed for any these galvanometers, and even if they had been listed, several publications indicated that the period on Muirhead Kelvin galvanometers could be adjusted over a significant range.

It turns out that manufacturers of galvanometers of the day generally did not specify the swing time of their galvanometers in the list of specifications



613.

Fig. 14. This deadbeat Kelvin galvanometer, made by Muirhead Company in 1893, was typical of one that Lodge may have used in his Oxford lecture; the external concave mirror for the speaking galvanometer was sold separately. (Muirhead & Co. *Electrical & Telegraphic Apparatus* catalog, 1893, p. 45)

that they published. This conundrum presented a lingering problem until several catalogs for Kelvin and D'Arsonval galvanometers dating to the 1920s were found. They provided the necessary explanation and data to allow an appropriate selection of an assumed swing time for Lodge's galvanometer. Here is what one catalog stated about the deflection of galvanometer indicators (needles or spots of light for reflecting galvanometers) and how the galvanometers could be critically damped:

> "PERIOD: The period as stated for each galvanometer is the undamped period, and is the time, in seconds, elapsing between two successive passages in the same direction through the position of rest. It is customary to take the period of a critically damped galvanometer as equal to its undamped period, for while the critically damped period is theoretically infinite, practically, a critically damped deflection is within about 1.5 per cent of its final position in the undamped periodic time.
>
> "EXTERNAL CRITICAL DAMPING RESISTANCE: This is the resistance which, when placed across the galvanometer terminals, will produce critical damping."[91]

Thus, the swing time of the galvanometer is equal to the undamped period, a specification that did appear in many galvanometer catalogs of the day. To clarify the above statement, the relationship between the undamped period and swing time is illustrated in Fig. 15,[92] where the step function response of a galvanometer is shown as a function of the damping coefficient ζ over the entire range of damping possibilities: undamped ($\zeta = 0$), underdamped ($0 < \zeta < 1$), critically damped ($\zeta = 1$), and overdamped ($\zeta > 1$). A critically damped galvanometer was often characterized as aperiodic or deadbeat. The period of a Kelvin reflecting galvanometer is determined by the resistance of the coil, selection of magnets, and degree of vacuum. A deadbeat response can be obtained by placing a shunt with the appropriate resistance across the galvanometer. (While shunts can reduce the sensitivity of the galvanometer, sensitivity was not an issue for the coherer circuit in

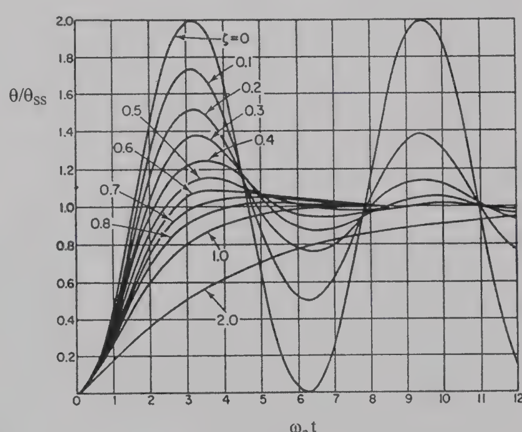


Fig. 15. The relationship between the undamped period and swing time is illustrated, where the step function response of a galvanometer is shown as a function of the damping coefficient z over the entire range of damping possibilities: undamped (z = 0), underdamped (0 < z < 1), critically damped (z = 1), and overdamped (z > 1). (Northrop, *Introduction to Instruments and Measurements*, 2005, p. 506)

wireless telegraphy that connected the galvanometer with a local battery.)

It is evident from this figure that the swing time of the critically damped galvanometer ($\zeta = 1$) is very close to the undamped period. Both are about 6½ units of the time scale shown for this galvanometer. It is also evident that the swing during the rising portion of the galvanometer response is approximately linear until the indicator reaches about 80% of its final value. Therefore, the rise and fall times of the indicator (spot of light or needle) are proportional to the pulse width of the applied stress, and equal the time to reach about 80% of the maximum swing. The swing shown in the figure reaches its 80% point at approximately one half of the undamped period. If one assumes that the remainder of the swing between 80% and 100% of the swing is linear—and rising at the same rate of the swing to the 80% point—then the 100% point will be reached in approximately two-thirds of the undamped period instead of the entire period. This approximation is appropriate because the galvanometer swing for most radiotelegraphic pulse widths of interest will be below the 80% point. This assumption will also greatly simplify the analysis with little error, and it favors the ability to interpret the galvanometer response, thereby making it a "best-case" assumption favoring Lodge's apparatus. In short, the one-way swing time for Lodge's damped galvanometer will be assumed to be two-thirds of the specification for the undamped period listed in catalogs.

After reviewing a number of catalogs by various manufacturers of both Kelvin and D'Arsonval meters published before 1904, there were no galvanometers to be found that had an undamped period of less than 3 seconds. The design points for the more sensitive galvanometers were between 5 and 20 seconds, with 10 seconds being a standard in the industry that was used for purposes of comparing sensitivity between galvanometers, and 5 seconds being the usual time for galvanometers that were used for lecture demonstrations. Of all the instruments in a number of the catalogs of the day, a table reproduced from the Cambridge Scientific Instrument Company catalog listed galvanometers that had the smallest undamped periods, and the smallest one in the table was 3 seconds (see Table 1).[93]

Since there was none below 3 seconds, an undamped period of 3 seconds (corresponding to a one way swing time of 2 seconds), was used in the analyses that follow. This selection is intended to be a best-case number for a galvanometer with the smallest possible swing that Lodge might have used. In fact, Lodge was never interested in minimizing the swing time of his galvanometer, because he admitted that he sent long and short pulses only in the context of his vision experiment—not letters in Morse code—so the time interval between sending a long pulse and a short pulse was not germane to his demonstration.

For purposes of modeling, the linear rate of rise of the indicator to the 80% point is extrapolated to the 100% point, which means the rise time for a step function of current that would produce the maximum swing is two-thirds

Table 1. Table from Cambridge Scientific Instrument Company catalog dated c. 1906 listing a galvanometer with a 3 second period.

Resistance of coil in ohms	Period of coil in seconds out of magnetic field	Deflection in mm. at 1 metre			1 mm. deflection at 1 metre produced by			Factor of merit
		per micro-amp	per micro-volt	per micro-coulomb	micro-amps	micro-volts	micro-coulombs	
7	→3.0	18	2.6	37	5.6×10^{-2}	3.9×10^{-1}	2.7×10^{-2}	90
7	8.0	139	19.8	110	7.2×10^{-2}	5.0×10^{-2}	1.9×10^{-3}	100
20	8.2	245	12	190	4×10^{-3}	8.2×10^{-2}	5.3×10^{-3}	110
20	3.5	53	2.6	100	1.9×10^{-3}	3.9×10^{-1}	1.0×10^{-2}	130
146	7.8	540	3.7	435	1.9×10^{-3}	2.7×10^{-1}	2.3×10^{-3}	123
400	8.3	757	1.9	590	1.3×10^{-3}	5.3×10^{-1}	1.7×10^{-3}	100

of 3 seconds, or 2 seconds. If the applied current pulse ends at two seconds, it will be assumed the indicator has reached the maximum value, and it will be assumed that the return to zero from the maximum value is the same as the time of its rise, namely 2 seconds. Since the response is linear, if the applied pulse width is 1 second, the indicator will rise to half the maximum on the scale in half the time (1 second) and return to zero in half the time (1 second).

Also, tests have shown if the maximum current is set to half the scale, the swing time will still be 2 seconds to half the scale point. Thus, it makes little difference whether the current limiting resistor in the galvanometer circuit is set for a swing to half the galvanometer scale position or to its full-scale position.

Best-Case Response of Lodge's Galvanometer

Using this model, it is possible to determine where the indicator of the galvanometer is during the entire reception of a word of Morse code for various assumed word rates. For this analysis, it is assumed that the battery in the coherer-galvanometer-battery circuit is sized to make the galvanometer reach the 100% point of the swing, and that the coherer is a perfect switch that faithfully reproduces the received pulses of electromagnetic radiation and turns them into current pulses that mimic the Morse code of the transmitted pulses.

The results of this modeling are shown in Fig. 16 for the word CODEX, one of a few standard words that have been used to represent one word of Morse code for modeling and measurement purposes. The Morse code representation for this word appears at the top of the figure with the appropriate spacings used in Morse code. The unit of time used in Morse code is the "dot space," which is the length of time for a single dot of code. The dot space depends on the speed of transmission. Since there are 60 dot spaces in a word of Morse code, a dot space of one second corresponds to

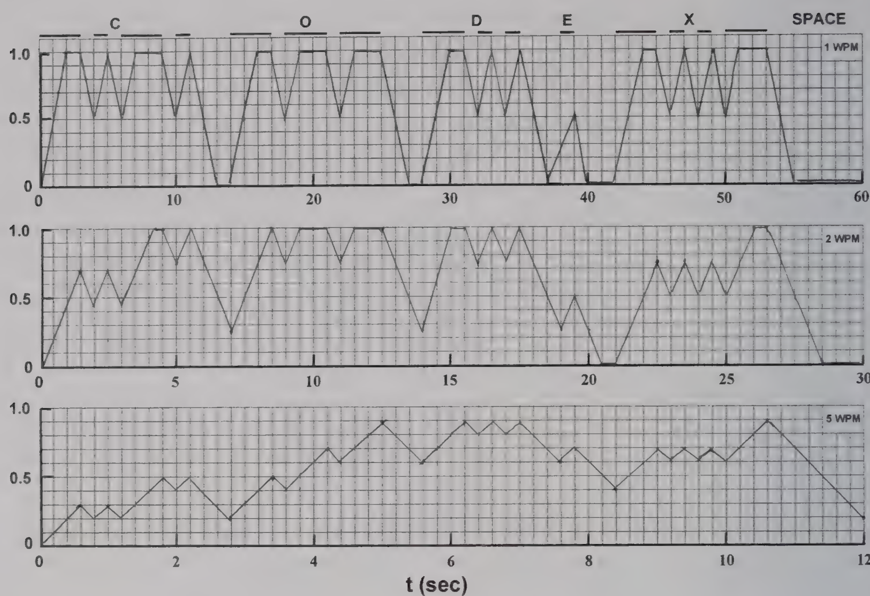


Fig. 16. Galvanometer needle position between 0 and full-scale deflection as a function of time for receiving the word CODEX at three different word speeds, as indicated in the upper right. The time scales for 2 and 5 wpm have been expanded as compared to 1 wpm for purposes of obtaining better resolution. (Author)

a speed of one word per minute. There are 60 dot spaces in the word CODEX, which are distributed as follows:

- One dot space for each dot (7 dots),
- Three dot spaces for 8 dashes (24),
- One dot space between the 10 dots and dashes within each letter (10),
- Three dot spaces between the four letters (12),
- Seven dot spaces placed at the end of every word (7).

Note that each pulse transmitted by a spark was on the order of 1 μsec in duration, and there were on the order of 100 sparks transmitted per second. At 10 words per minute, each dot space was 0.1 sec, so each dot consisted of 10 very short pulses, and each dash consisted of 30 very short pulses. The total time taken up by the sparks that produced any character of Morse code was insignificant compared to the basic time unit for a dot space of 0.1 sec. Thus, the exact length of each pulse was irrelevant to the Morse code scheme, and the duration of each spark pulse contained no information.

In this analysis, the coherer is assumed to be perfectly self-restoring such that it reproduces the time history of the Morse code signals that were transmitted. The word CODEX is represented on the top scale by 60 intervals of the x-axis, the last seven being in the "off state," which was used to indicate a

separation between words. There is no time scale on this signal—just the relative lengths of the dots, dashes, and spaces, as indicated above. The actual time scales depend on the word rate used to calculate the responses of the galvanometer, three of which are shown in the lower portion of the figure for word rates of 1, 2, and 5 words per minute respectively. The time scales are different for each case because it is not possible to clearly show needle positions on the same time scale for 1, 2 and 5 words per minute.

The resulting response consists of the relative position of the galvanometer indicator between 0 and 100% of full-scale deflection, the latter being represented by 1 on the vertical scale. The time scale for the first response shown is 60 seconds; since the word CODEX has sixty dot spaces, this response corresponds to 1 word in 60 seconds or 1 wpm. The second scale of 30 seconds corresponds to a word rate of 2 wpm, and the third scale of 12 seconds corresponds to a word rate of 5 wpm.

It is evident from these calculations that the galvanometer indicator is not able to return to zero for even one word per minute. It is also evident that the indicator will return to zero after each pulse only when the dot space is longer than one swing time of the needle, which for Lodge's galvanometer is believed to be no less than 2 seconds. Since the galvanometer swings have no set zero base, it is impossible to interpret the needle swings and spacings for any word rate greater than even one word per minute—and that is with all the best-case assumptions in terms of indicator swing speeds.

Galvanometer Measurements

The results of the analysis presented here can actually be tested with a modern D'Arsonval galvanometer that has a swing time slightly faster than the swing time of any galvanometer Lodge could have used. An Omnigraph, made by the Omnigraph Corporation, was used to generate Morse code signals for word rates between 1 and 20 words per minute, and a Simpson 260 volt-ohm-milliammeter (VOM) was used as a surrogate galvanometer to determine if the needle swings could be interpreted as letters and words of Morse code. It was determined that the round trip swing time for the 2.5 volt scale on this VOM is 2.6 seconds. This was determined by applying a voltage of 2.5 volts and measuring the round trip excursion to 95% of full scale and back to 5% of full scale. To measure the time more accurately, the 2.5 volt pulse was applied ten times, and the measured result was 26 seconds, which amounts to 2.6 seconds for a single round trip swing. While the one way swing was not measured directly, the estimated time for the swing up appeared to be very close to the time for the swing down, which was to be expected.

The analyses presented here was put to the test by observing the swings on the VOM using actual Morse code signals generated by the Omnigraph, which was capable of creating Morse code at various speeds between approximately 1 and 20 wpm (see Fig. 17). There is no possible way to interpret the swings of the galvanometer for anything over one word per minute. The needle swings wildly, hardly ever coming to rest at zero. What

Fig. 17. Apparatus used to demonstrate actual galvanometer deflections using an Omnigraph to generate words at rates between 1 and 20 wpm and a Simpson 260 VOM with a one-way swing time of 1.3 seconds on the 2.5 volt scale. (Author)

is really difficult to determine is whether the brief inflections represent a one dot space or three dot spaces.

Unfortunately, it is not possible to represent the dynamic swings of the VOM needle in this stationary printed format. However, I plan to prepare a video of the response and make it available on the AWA website at some point in the future.

Takeaway

In 1907, Lodge claimed he sent a long pulse and a short pulse at his 1894 lectures, but he admitted he had not sent any letters or words in Morse code. Lodge was able to distinguish between long and short pulses at his lecture demonstration only because they were widely spaced, and he allowed enough time to pass between pulses so the indicator of his galvanometer could return to the baseline between long and short pulses. It has been demonstrated that the best galvanometer of the day was not adequate to interpret needle swings at word speeds of greater than one or two words per minute, if that. This was a clear demonstration that the ability to send long and short pulses, without considering the spacing between pulses, is not adequate to show the possibility of actual signaling, that is to say, receiving and interpreting Morse code.

It was only after Lodge learned Marconi had used a Morse inker that Lodge replaced his galvanometer with a Morse inker. Lodge first learned that Marconi had used a Morse inker at the meeting of the British Association on September 21, 1896, and he learned more details of Marconi's apparatus from Preece's lecture on June 4, 1897. On June 16, 1897, less than two weeks after Preece revealed the details of Marconi's apparatus, both Lodge and Marconi demonstrated their

respective telegraph systems at an evening soirée at the Royal Institution, where Lodge had replaced his galvanometer with a Morse inker:

> "In a spacious apartment adjoining the entrance hall Mr. Preece and Signor Marconi demonstrated their respective methods of "Signaling through Space without Wires," while in a room overhead Dr. Alex. Muirhead exhibited an apparatus for performing the same useful operation, 'as practiced by Dr. Oliver Lodge in 1894,' the only addition to Dr. Lodge's original apparatus being that it was now adapted to a Kelvin ink-writer telegraph, the Marconi apparatus, on the contrary, being adapted to a sounder. So far as we were able to judge, the Lodge system worked satisfactorily, the transmitter being at a distance of only a hundred feet or so."[94]

Lodge surely had tested his galvanometer circuit before this demonstration and found that it would not work for Morse code, so he copied Marconi's apparatus by replacing his galvanometer with a Morse inker.

The fact is that no known practical radiotelegraph system ever used a galvanometer as a detector of Morse code messages. Also, the galvanometer was not used in any of the known systems using electric-field or magnetic-field induction methods used before Hertz that actually demonstrated receiving messages. Wireless pioneers before Hertz, such as David Hughes, Amos Dolbear, Thomas Edison, and William Preece, all used telephone receivers as the detector for messages or letters. Some of the wireless pioneers used galvanometers for test purposes, but only to measure signal strengths, not to detect and interpret Morse code messages.

Lodge's Antenna Was the Achilles Heel for Practical Ranges

The Achilles heel in Lodge's apparatus for reaching practical ranges was his antenna apparatus, which consisted of a single ordinary dipole antenna that radiated short Hertzian waves of 6 meters from a dipole radiator. There was no deliberate antenna on his Branly coherer circuit, which he used as a receiver. There was only a loop of wire connecting the coherer, battery, and galvanometer together. Furthermore, there was no mention of tuning the coherer circuit to the wavelength emitted from the transmitter.

A number of historians have credited Marconi's long monopole antennas of approximately the same length to be the secret to his success. Other historians have asserted that there was nothing new about Marconi using monopole antennas, since others had used two monopole-like antennas before him. What these other historians did not say was that none of the wireless pioneers who used two vertical wires before Marconi ever sent messages to practical distances, as evidenced by the fact that not one such apparatus was ever used commercially. Pioneers who used monopole-like antennas before Marconi used electrical sources with wavelengths in the audio frequency range so they could be detected with telephone receivers, which had a frequency response that peaked well below 10 kHz (30 km). The wavelengths of

audio signals are so long that they do not produce significant Hertzian radiation when applied to monopole or dipole antennas of any practical height. Wireless pioneers who used audio frequency sources with monopole-like antennas were limited to a demonstrated range of two to three miles.[95]

Marconi was the first to use two monopole antennas that operated by radiating and receiving electromagnetic waves. Marconi was also first to discover what became known as Marconi's law by performing experiments that showed the maximum range of his apparatus using Hertzian radiation was proportional to the square of the product of the transmitter and receiver heights. Two tall monopole antennas radiating long wavelengths were the secret to early practical, long-distance radiotelegraphy.

Marconi Discovers Marconi's Law

By May 13, 1897, Marconi had established Marconi's law from the empirical data he had taken by varying the height of the vertical wires on his transmitting and receiving antennas and observing the distance he was able to transmit and receive messages. The distance he achieved in 1897 ranged from a few miles at Salisbury Plain to nine miles across the Bristol Channel, depending on the height of the vertical wires. Simply stated, Marconi's law held that the maximum range d of a radiotelegraph system was proportional to the square of the antenna height h when the transmitter and the receiver antennas are of the same height. The expression for this square law can be expressed in several ways, but the one that is most useful for the analyses to follow is $d = kh^2$ where k is a constant of proportionality. This constant, with dimensions of inverse distance, was generally different for each system.

This result elicited a great deal of interest among wireless pioneers in a number of countries, most notably in England, Germany, Italy, France, and the United States. The Italian professor Moise Ascoli was one of the first who took note by providing an explanation of Marconi's law in a paper he published dated August 1, 1897.[96] He noted that the capacity of a vertical antenna wire increased in proportion to its height for wire heights of interest to radiotelegraphy. The increased capacity caused additional charge to accumulate in the transmitter antenna circuit during the charging phase of each pulse. With the gap spacing of the spark unchanged, the discharge voltage was the same, but Ascoli asserted the current in the antenna circuit was in proportion to the increase in charge. Thus, the maximum current in the antenna circuit, which was proportional to the charge, would have been proportional to antenna height.

Fleming provided a simple explanation using Professor Ascoli's observation and arguments involving proportionalities, which he represented by the symbol $\propto$.[97] He assumed the electric field E_R at the receiver antenna was proportional to the current in the transmitter antenna I_T and noted that the electric field for electromagnetic radiation in the far field was inversely proportional to distance d:

$$E_R \propto I_T/d.$$

He then observed that the current I_R in the receiving antenna was proportional to the incident electric field times the height of the antenna h. This assumption is only valid for electrically short receiver antennas, which applies to Marconi's monopole receiver antenna when its height is approximately equal to or less than the transmitter antenna height. Substituting I_T/d for E_R, the current in the receiver becomes:

$$I_R \propto hE_R \propto hI_T/d.$$

The current in the transmitter circuit was proportional to the capacity, which was proportional to height: $I_T \propto h$. Substituting h for I_T in the above expression results in Marconi's law for the current in a receiver produced by a current in a transmitter located at a distance d from receiver:

$$I_R \propto h^2/d.$$

Pioneers in other countries quickly verified Marconi's results independently, although certain limitations to Marconi's law were soon noted. While Marconi's law was observed in data for a number of different systems, albeit with different proportionally constants, it was also found that the proportionally constant for the same apparatus could be different at different locations. Specifically, the range appeared to be much greater over seawater than over dry land. This was due to the fact that a vertical monopole antenna is more efficient when it is driven above a highly conducting horizontal ground plane that extends for a distance equivalent to at least one or two antenna heights from the base of the monopole antenna.

Marconi and others also noted that the maximum range determined by experiment was actually somewhat greater than the square law predicted, particularly for monopole antennas of greater heights. There must have been an upper limit to the distance, although it was not clearly established because of ongoing improvements to the apparatus, which changed the constant k. Of course, there was also a lower limit to the range of applicability, since the receiving system had to be in the far field of the radiating antenna before the Hertzian waves formed and began to fall off as $1/d$.

Details of Marconi's discoveries during the period between 1896 and 1898 were summarized in detail in two important documents, one published by Capt. W. D. Brett, R.E. in 1897,[98] and a second published by Capt. J.N.C. Kennedy, R.E. in 1898.[99] Both were British Royal Engineers (R.E.) who observed and assisted in a number of Marconi's field tests under the supervision and direction of the British General Post Office. Of particular interest in these documents are descriptions of the experiments Marconi performed that resulted in the square-law relationship. Brett also described experiments that he had performed using one of the receivers Marconi had used during this early period.

There is one additional point about Marconi's law that is rarely mentioned in the literature, but is important for any analysis. It was not always possible to make the height of the transmitter and receiver antenna equal. For example, the maximum height of a vertical wire on a ship was often shorter than the vertical

wire at a ground station. In that case, it was found that Marconi's law could be more generally expressed as the range being proportional to the product of the heights of two antennas ($h_1 \times h_2$). John Gavey, Principal Technical Officer at the British GPO, made the following observation at a presentation by Brett on December 9, 1897:

> "It is found that instead of two vertical conductors of the same height two of widely different dimensions giving the same product are used and equally good signals are obtained. On looking at the question theoretically there appears to be no reason to expect a different result."[100]

However, there is a limit to this assertion as the length of a vertically polarized receiving antenna becomes much longer than the length of a vertically polarized radiating antenna. For example, the response of a simple vertical dipole receiver antenna approaches a null as its length approaches twice the length of a second vertical dipole radiating at its natural resonant frequency.

The data that Marconi collected from his original apparatus in experiments over earth at Salisbury Plain in late 1896 and early 1897 are quite different from results he obtained over water at the Bristol Channel and Spezia, Italy, in mid-1897. The range of his apparatus over seawater was considerably greater than the ranges over earth for apparatus that had equal vertical wire heights. The data over seawater is more relevant for comparing Marconi's results using vertical wires with Lodge's results using a dipole radiator. The efficiency of radiation from a monopole radiator approaches that of a dipole radiator only when the ground plane under the monopole is a good conductor. Poorly conducting soil around the base of a monopole introduces losses in the driving circuit for the transmitter, losses that do not occur for dipole radiators in free space.

The data points that Marconi obtained over seawater in mid-1897 were few in comparison to the data he had taken at Salisbury Plain, but they are particularly relevant for the analysis that follows. The three well-documented data points over seawater included two very different ranges at the Bristol Channel in May 1897, which occurred in the presence of Captain Brett and other observers on behalf of the British GPO, and one of an intermediate range that took place in the Gulf of La Spezia, Italy, in the presence of Luigi Solari, an officer of the Italian Navy (see Table 2). In the third column of this table, h^2 represents the product of the heights of the transmit

Table 2. Data taken over water by August 1897 supporting the validity of Marconi's law. (Multiple sources)

Test Location Over Water	Maximum Distance (d)	Product of Antenna Hgts $h^2 = (h_T \times h_R)$	Ratio $k = d/h^2$
Bristol Channel[a]	5,400 m	(30 x 30) m^2	6 m^{-1}
Bristol Channel[b]	14,000 m	(48 x 30) m^2	9.7 m^{-1}
Gulf of La Spezia	12,700 m	(34 x 34) m^2	10.9 m^{-1}

[a]Lavernock Point to Flatholm; [b]Lavernock Point to Brean Down

and receive antennas, which were different for the experiment at the Bristol Channel on May 13, 1897, when the transmit antenna was raised from 30 to 48 meters in order to communicate to the receiver at Brean Down, a distance of 14 km from the source at Lavernock Point.

The demonstration at La Spezia took place in July 1897,[101] immediately after the successful tests at the Bristol Channel.[102] Thus, the apparatus used at both sites was the same, and it was the original apparatus described in Marconi's seminal patent. Later experiments were performed under more controlled conditions, and the resulting data clearly confirmed the square-law relationship. One set of data was particularly noted by the Italian Professor Domenico Mazzotto in his acclaimed book, *Wireless Telegraphy and Telephony*. The data were taken by Camille Tissot, a French naval officer and pioneer of wireless telegraphy, who confirmed Marconi's law in controlled experiments on a specific system design that appears to be a somewhat more efficient apparatus than Marconi used at the Bristol Channel (see Table 3).[103]

For example, Marconi reached a distance of approximately 14 km at Bristol Channel with a transmitter antenna height of about 48 meters, which resulted in $k = 6.1\ m^{-1}$. In contrast, Tissot's apparatus reached a distance of 13,500 meters with an antenna height of 25 meters, which resulted in $k = 12\ m^{-1}$, twice as large as Marconi's apparatus. It would appear that Tissot's apparatus was more efficient than Marconi's original apparatus, but it may also be due to a little-known fact that the maximum range to detect signals for a given radiotelegraphic system was observed to be much greater than the distance that intelligible messages could be reliably received.[104] It is probable that Tissot's range data was taken based on the criterion of the minimum detectable signals as opposed to range that intelligible messages could be received. Note that many wireless pioneers and historians stated ranges of telegraphic apparatus based on reported ranges of detectable signals rather than the ability to receive intelligible signals.

Table 3. Tissot's data demonstrating Marconi's law.

Antenna Height (h)	Maximum Distance (d)	Ratio $k = d/h^2$
12 m	1,800 m	$12.5\ m^{-1}$
20 m	4,500 m	$11.3\ m^{-1}$
25 m	7,500 m	$12\ m^{-1}$
30 m	13,500 m	$15\ m^{-1}$
35 m	22,000 m	$18\ m^{-1}$
45 m	40,000 m	$20\ m^{-1}$

Referring to Table 3, the ratio k is relatively constant for antenna heights less than 25 meters, but the ratio slowly increases as the antenna height increases from 25 to 45 meters. These data support Marconi's earlier observations that the range of his system was generally somewhat greater than the square law predicts. This result also suggests that the explanations put forth by Professors Ascoli and Fleming may be oversimplified.

Based on this and similar data, Mazzotto made the following statement, which was echoed by many early wireless pioneers: "Sky rods (antennas) constitute one of the most essential parts in wireless telegraphy." It will be shown in the

next section that his statement is true, and that without both of the very high vertical antennas of approximately the same height that Marconi introduced in 1896, the range of Lodge's apparatus would never exceed the very short ranges that Lodge measured and predicted in 1894.

Maximum Range Analysis of Lodge's Apparatus

Lodge gave the subject of dipole and spherical radiators special attention in his 1894 lectures, identifying no fewer than nine different images of radiating dipoles and spheres that emitted wavelengths from a few centimeters to 30 meters. The shortest wavelengths were radiated by a small sphere with a diameter of a few inches, and the longest wavelength was radiated by Lodge's large Hertz vibrator. One vibrator described as a "standard" or "ordinary" Hertz vibrator emitted waves of 6 meters, and another described as a "great" Hertz vibrator emitted wavelengths of 30 meters: "Here is a great one giving waves 30 meters long, radiating while it lasts with an activity of 100 H. P. [horsepower], and making ten million complete electric vibrations per second."[105]

In several documents, Lodge claimed that he used the ordinary Hertz vibrator to transmit and receive short and long pulses in his 1894 lectures. It is highly unlikely that Lodge used his largest Hertz oscillator for his vision experiment. One reporter who attended the lecture at the Royal Institution pointed out that Lodge had hung his largest Hertz vibrator from the ceiling of the lecture room and that it did not work well because the reflections off the gilded wall of the room interfered with the direct radiation.[106] Since Lodge claimed that the source of radiation for his configuration that sent long and short pulses was in another room, it could not have been his largest Hertz oscillator. With regard to his large oscillator, Lodge explained in an earlier paper how he used the large oscillator: "The plates and connecting rod are hung from a high gallery, so that everything occupies one plane."[107]

It should be obvious from the previous discussion that Lodge could not achieve long distances without a long vertical wire radiating long wavelengths and a long vertical antenna collecting the energy received from long wavelengths. In fact, the range of Lodge's apparatus can be predicted by using the data used to demonstrate the validity of Marconi's law. Before presenting the results of such a calculation, it must be noted that Lodge claimed the difference between the range of his apparatus and the range of Marconi's apparatus was due to the larger power Marconi used. Here is what Lodge wrote to *The Times* upon learning of the details of Marconi's patent in June of 1897:

> "Signor Marconi uses nickel and silver filings in a lower vacuum, and *by employing greater power he has obtained signals over much greater distances* [emphasis added]; moreover, instructed primarily by Professor Righi, and aided in his trials by the British Post Office, he has worked hard to develop the method into a commercial success."[108]

Marconi's detractors seized on Lodge's argument of greater power and turned it into a mantra for claiming that the only difference between Marconi's apparatus and Lodge's apparatus was one of power. Here is testimony given by Charles S. Bright, a noted telegraph engineer, before the House of Commons Radiotelegraphic Committee in 1907:

> "The main difference between Marconi's apparatus and that of Lodge was the connection with earth and the employment of an aerial wire supported on a high mast. There was also a kite at the top of the aerial similar to that described by Edison in an expired patent which the Marconi Company have seen fit to purchase. By these means—but more especially by increase of power—in addition to capital expenditure, Mr. Marconi gradually increased his range to considerable distances; and undoubtedly he and his business friends have done more than any man in developing the commercial possibilities of that system of telegraphy, which turns to account [e.g., profits from] Hertzian waves. But the difference between Lodge's early achievements and that of Marconi is, after all, only one of degree, in which the dates of their respective work must be borne in mind."[109]

The claim by Lodge and Bright that Marconi achieved more range because he used more power is a red herring. It will be shown that Marconi achieved a greater range because he used longer vertical wires on both his transmitter and receiver. The longer wire on Marconi's transmitter did radiate more energy and power, but without an equally long monopole antenna at the receiver, Marconi's range would also have been doomed to a range of less than a mile. This will be shown by applying Marconi's law to both Lodge's and Marconi's systems.

Lodge's ordinary Hertz oscillator transmitter consisted of a dipole antenna with a total length $\ell_T = 3$ meters that radiated wavelengths of approximately 6 meters. While there was no specific antenna attached to the coherer circuit, there was some equivalent but unknown dipole antenna length ℓ_R that would have represented the coupling of energy to the coherer in the Branly coherer circuit. With this limited information, it is possible to apply Marconi's law to determine what the maximum range of Lodge's apparatus would have been. The basic equation used for Marconi's law is

$$d = k\ell_R\ell_T,$$

where d is the range, ℓ_T is the height of the transmitter antenna, ℓ_R is the height of the receiver antenna, and k is the square-law constant for a particular system. The two unknown quantities are the constant k for Lodge's apparatus and the effective length ℓ_R of the dipole representing the receiver circuit. It turns out that the product of the two unknowns $k\ell_R$, a dimensionless quantity, can be determined from the above equation using Lodge's data from the experiment he described in his 1894 lecture ($d = 60$ m and $\ell_T = 3$ m):

$$k\ell_R = d/\ell_T = (60 \text{ m})/(3 \text{ m}) = 20.$$

The one parameter that can be changed in Lodge's apparatus without changing the basic design is the length of the Hertz dipole radiator. It has been pointed out that Lodge developed a larger version of a Hertz oscillator in 1892 that he claimed radiated 30 meters.[110] Assume that the length of the ordinary Hertz dipole radiator Lodge said he used is increased from the 3 meters he radiated with the ordinary Hertz vibrator to 48 meters, thereby matching the total height of Marconi's monopole antenna at Bristol Channel. A 48 meter half-wave dipole antenna would have radiated wavelengths of almost 100 meters, more than 3 times as long as Lodge's largest Hertz vibrator that radiated 30 meters, and it would have radiated wavelengths of about half the length of that radiated by Marconi's 48 meter monopole.

This increase in length would have increased the capacity of the discharge circuit in Lodge's extrapolated apparatus by a factor of 16, thereby increasing the radiated energy and extending the range of Lodge's apparatus. The extrapolated range *d* of Lodge's apparatus would have increased by a factor of 16 from 60 meters to 960 meters:

$$d = k\ell_T\ell_R = 20 \times 48 \text{ m} = 0.96 \text{ km}.$$

This dispels the assertion that the only difference between the two systems was an increase in power. Without the addition of an equally high vertical wire on the receiver, Lodge's apparatus would never have reached a practical range. Clearly, Lodge did not understand the importance of having two tall monopole antennas of approximately equal height to obtain long ranges for radiotelegraph systems. (It is more likely that Lodge did not consider an antenna for the detector circuit in his Oxford lecture because he had no interest in radiotelegraphic apparatus at that time.) It was not just more power radiated from the transmitter that extended the range of Marconi's apparatus, and Marconi's apparatus was not merely an extension of Lodge's apparatus.

If Lodge had used a dipole antenna for the *receiver* in his 1894 experiment and increased its length by the same factor of 16 as the transmitter antenna, his range would have increased from 0.96 km to 16 × 0.96 km = 15.4 km, almost identical to the 14 km range Marconi demonstrated across the Bristol Channel. This illustrates the importance of the tall vertical wire at the receiver, which has nothing to do with an increase in power at the transmitter.

The same analysis can be applied to Marconi's apparatus to show that Marconi's apparatus would not have been practical if his antennas were scaled down to radiate and receive the same short wavelengths that Lodge used at his 1894 lectures. The equivalent height of Marconi's quarter wavelength monopole antenna needed to radiate the same wavelength as the ordinary Hertz oscillator (6 meters) would have been 1.6 meters. Using the Marconi law constant of 6.1 from Table 2, the range of Marconi's apparatus with two 1.5 meter vertical wires would have been

$$d = kh^2 = 6.1 \times (1.5)^2 = 14 \text{ meters}.$$

Actually, the range would have been somewhat greater, because with a vertical

wire as short as 1.6 meters, the capacitive loading of the plates Marconi used with such short vertical wires would have increased the effective height of his monopole antennas.

Takeaway

It is important to understand that the critical difference between Lodge's apparatus and Marconi's apparatus was not just a difference in energy; it was a difference in the use of two large antennas tuned to nearly the same frequency. It is clear that Lodge was not aware of the need for an antenna on a radiotelegraph receiver in 1894, and more specifically two large antennas of approximately the same height. It is also clear that he never could have discovered Marconi's square-law relationship by tests in his laboratory or in his lecture rooms, both of which were confined to small dimensions. This should be no surprise because he showed no interest in radiotelegraphy, much less any interest in extending the range of his apparatus. It is clear that Lodge was interested in smaller antennas with small wavelengths so he could reproduce the experiments of Hertz in the confines of a laboratory or lecture room more easily, not because he had any interest in demonstrating radiotelegraphy.

Genesis of Lodge's and Marconi's Apparatus

Immediately after Marconi's patent was published in 1897, Lodge claimed in a letter to *The Times*: "I myself showed what was essentially the same plan of signaling in 1894.... My apparatus was substantially the same as that now used by Signor Marconi."[111] His assertions were not specific nor were they convincing. An editor of the *Electrician* made a much bolder claim: "In fact Dr. Lodge published enough three years ago to enable the most simple-minded 'practician' to compound a system of practical telegraphy without deviating a single hair's-breadth from Lodgian methods."[112]

To this day many historians have claimed that Marconi invented nothing new and merely copied Lodge's apparatus—to wit, this claim was made in the recently published book, *A Pioneer of Connection* referenced previously: "Lodge published the lecture as *The Work of Hertz and Some of His Successors* later that year; however, stunned by Marconi's patent for a means of wireless telegraphy (and one that used an improved version of his apparatus) in 1897..."[113]

As far as I am aware, no historian has refuted this claim by comparing Marconi's apparatus with that of Lodge to identify the critical similarities and differences, nor has any historian compared Lodge's apparatus with that of other wireless pioneers to document that it was Lodge who copied the apparatus of others. It should be clear from the previous text that Marconi did not copy any of Lodge's work. It was actually Lodge who copied the work of Hertz and Branly in 1894, Lodge who copied the use of Marconi's Morse inker in 1897, and Lodge who copied Marconi's tall antenna designs in his complete patent application filed in 1898. A summary of the genesis of both Lodge's and Marconi's early Hertzian wave apparatus using coherers as a detector is summarized in

Table 4, followed by a few comments about the entries.

Genesis of Spark Sources

Lodge stated that he used an ordinary Hertz vibrator to send long and short signals that showed the possibility of signaling: "The sending instrument was a Hertz vibrator actuated by an ordinary induction coil set into action by a Morse key. The apparatus was in another room, and was worked by an assistant."[114] In Lodge's preliminary application for his first wireless telegraph apparatus patent filed on May 4, 1897, he referred to an image of a Hertz vibrator, describing it as "the simplest arrangement for an emitter and receiver heretofore in use." There was nothing new about this oscillator. He copied it directly from Hertz with no obvious changes or improvements.

Marconi used the oscillator described in Righi's paper published in 1893 for his source of sparks (see Fig. 18).[115] The version Marconi used was photographed beside Marconi for *McClure's Magazine* published in March 1897 (see Fig. 19).[116] The Righi oscillator described in Marconi's seminal UK Patent 12,039 differs from the Hertz and Lodge oscillators in two important ways. First, the two large sparking knobs were immersed in "a vessel which is filled with di-electric liquid preferably vaseline oil slightly thickened with vaseline. The oil or insulating liquid between the sphere labeled with a double *e e* increases the power of the radiation and also enables one to obtain constant effects, which are not easily obtained if the oil is omitted."[117] The relative dielectric constant of vaseline is between 2 and 3, which would have more than doubled the capacity between the knobs. As a

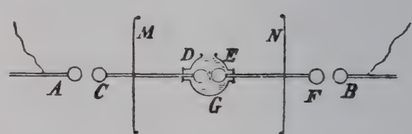


Fig. 18. The Righi oscillator that Marconi used to generate sparks for his transmitter was described by Righi in a paper he published in 1893, well before Lodge's lectures in 1894. (Righi, *Atti della Reale Accademia dei Lincei*, Vol. II, April 30, 1893, p. 333)

Table 4. Genesis of Lodge and Marconi Apparatus (Author)

Apparatus	Lodge	Marconi
Spark source	Copied Hertz oscillator with two knobs and air gap spacing.	Copied 1893 Righi 4-knob oscillator with two large knobs immersed in oil.
Transmitter and receiver antennas	Copied ordinary Hertz dipole radiator; no deliberate antenna used on receiver circuit.	First to use a tall monopole radiator of Hertz waves and a monopole of equal height to receive waves.
Receiver circuit	Copied Branly's 1890 coherer circuit with no antenna: battery, Branly filings coherer, and a galvanometer to detect waves	Copied Branly filing coherer; created a two-circuit configuration with a high-resistance relay, and a second battery connected to a Morse register.
Coherer tapper	Created a novel clockwork tapper, but with the tap timing unrelated to incident waves.	Created a tapper activated by each pulse for instant restoration, thereby mimicking a self-restoring coherer.

SIGNOR MARCONI AND HIS EARLIER APPARATUS FOR TELEGRAPHING WITHOUT WIRES.
From a photograph taken by Russell & Sons, London, expressly for McClure's Magazine.

Fig. 19. Marconi was photographed with his version of the Righi oscillator for an interview appearing in *McClure's Magazine*. (H.J.W. Dam, *McClure's Magazine*, Vol. 8, March 1897, p. 387)

result, the charge that accumulated on the spheres prior to the discharge would have doubled for the same applied voltage. This feature would have increased the current flowing in the antenna. The second reason for using the oil was to prevent oxidation of the sphere at the point of discharge, thereby eliminating the need for constant polishing to maintain proper sparking, something that Lodge said he had to do often to maintain proper sparking.

Some historians have claimed that Righi's oscillator used by Marconi was inspired by Lodge's lecture at Oxford in 1894. For example, referring to Lodge's Oxford lecture, Peter Rowlands wrote: "The apparatus it [Lodge's lecture] described was immediately taken up in Italy by Augusto Righi, in Russia by Alexander Popov, and in India by J. C. Bose, who all acknowledged Lodge's influence. In addition, Righi's work was the immediate inspiration for that of Guglielmo Marconi."[118] However, the Righi oscillator that inspired Marconi's source was described by Righi in a publication dated April 30, 1893,[119] more than a year before Lodge's Oxford lecture. Therefore, Righi's oscillator design could not have been inspired by Lodge's lecture. In fact, Righi credited his inspiration for sparking spheres immersed in oil to the Swiss scientists, Édouard Sarasin and Lucien de la Rive, who published this idea in 1892.[120] Righi did not credit Lodge for the inspiration of his oscillator.

Genesis of Antennas

Lodge used the ordinary Hertz dipole oscillator as described above for his source of Hertzian radiation. This source radiated wavelengths of approximately 6 meters. It was Lodge who copied his transmitting antenna from Hertz. Lodge did not use any antenna on his Branly receiving circuit. The coherer was excited by the loop of wire that connected the components together.

Marconi described two types of source antennas, parabolic reflectors for directional communication, and two monopole antennas of the same height for omnidirectional communication. The monopole antennas are of interest here because Marconi used them to demonstrate long-range telegraphy. Marconi was the first one ever to use two long monopole antennas, both tuned to the same frequency by making them about the same height, to transmit and receive electromagnetic waves. He was also the first one to discover that the maximum range for receiving a signal or a message from a transmitter was proportional to the square of the height of the antennas, a phenomenon known as Marconi's law.

Many historians claim that Marconi was not the first to use two monopole antennas and therefore he did not invent anything new. These historians fail to distinguish between "raised conducting surfaces" that resembled monopole antennas but actually provided the capacitive coupling needed for the method of electric-field induction, such as that described by Thomas Edison in his 1885 patent.[121] Marconi used what we now call "antennas," which radiate electromagnetic energy that actually detaches from the antenna and propagates for long distances through free space. He was also the first to radiate and receive long wavelengths, which were critical to achieving long distances. Marconi clearly did not copy Lodge's antenna apparatus.

Genesis of Coherer Receiving Circuits Including Tappers

Lodge copied Branly's receiver circuit consisting of a Branly tube-of-filings coherer in series with a galvanometer and battery—and with no deliberate antenna, much less a large antenna. It is now clear that neither Branly's nor Lodge's galvanometer operated fast enough for an operator to interpret Morse code at a practical data rate. This was one of two Achilles heels for his system. Also, Lodge's clockwork tapper was not timed with the incident radiation pulses; taps at the wrong time could cause random errors in the interpretation of Morse code.[122]

Lodge also claimed that he improved on Branly's iron filings coherer, but there is no evidence that he actually improved on it. After all, there is no record he ever used the 1894 apparatus to actually receive messages at practical data rates. Also, Branly made many different coherers with different materials and with non-conducting liquids to prevent oxidation. How could Lodge possibly have known that his coherer was an improvement over any or all versions of coherers that Branly developed between the end of 1890 and the end of 1893?

In Marconi's speech when he received his Nobel Prize in 1909 for his

contributions to the development of radiotelegraphy, he claimed he copied Branly's coherer, not Lodge's coherer: "My first tests were carried out with an ordinary Hertz oscillator and a Branly coherer as detector, but I soon found out that the Branly coherer was far too erratic and unreliable for practical work."[123] There is evidence to support his assertion that he used Branly's coherer as the basis for his coherer in the form of a letter Marconi wrote to Branly paying him tribute. This letter from Marconi to Branly surfaced during an interview of Branly by the then well-known French scientist "Ariel" circa 1923. Ariel documented this letter by writing the following:

> "The letter [from Marconi] paid tribute to the splendid work of Dr. Branly that had some recent experiments give such fine results. 'The coherer,' the Doctor continued, 'was used as a means of detection for a number of years. It seemed to make a big stride forward in wireless telephony. That period of my life, when I was in communication with Signor Marconi, was one of the busiest and happiest.' "[124]

To be sure, Marconi did not ultimately copy Branly's coherer. Captain Kennedy, a representative of the British GPO, claimed he performed a number of experiments with many coherers including the coherer Marconi used in his apparatus. Here is what he had to say about Marconi's coherer:

> "It has been said that Marconi deserves credit for *slightly* improving the coherer. I have tried experiments with all sorts of coherers, and Mr. Marconi's is the only one that will give an intelligible message at all. So that I think if you alter the word 'slightly' to 'enormously' improving the coherer, you will have about the correct appreciation of his work. There is such a number of details to be worked out before success is obtained, that the difficulties in the way are hardly appreciated till one commences to experiment oneself."[125]

Marconi surely did not copy either Branly's or Lodge's coherer receiver circuit. Instead, he used a Morse inker in lieu of a galvanometer, and his tapper was triggered by each incident pulse, effectively making it a self-restoring coherer. This circuit was unique to Marconi, despite claims by critics that Popov had published the same tapper circuit. This is false; it is no secret that Popov admitted his storm detector was not capable of receiving Morse code.[126] And Popov never claimed that he sent letters or messages in Morse code to his storm detector. Certain claims first made by Soviet Russia more than twenty years after the fact are contradicted by contemporaneous documents, and they were made so late that they have no bearing on who invented radio more than 20 years earlier. Marconi was also the first to use a long monopole antenna to receive electromagnetic radiation in his receiver circuit, which was the secret to long-distance radiotelegraphy in the early days. He surely did not copy tall monopole antennas from Lodge's or Popov's apparatus.

Lodge Copied Marconi's Apparatus (1897–8)

In 1897 and 1898, Lodge copied two of the most important features of Marconi's apparatus, neither of which were mentioned or described in the apparatus Lodge claimed he used in his 1894 demonstrations: 1) a Morse inker and battery in a second circuit, excited by a relay actuated by the coherer, to record telegraphic letters and messages, and 2) very tall monopole antennas for both the transmitter and receiver, both tuned to the same wavelength by making them approximately equal in height. It has already been shown that these two features were the key to Marconi's achievement of transmitting messages to a distance of 14 km across the Bristol Channel at practical words rates of greater than 10 words a minute on May 13, 1897. Lodge did not use either of these features in his 1894 lectures. However, he did introduce them into his system, but only after learning that Marconi had used them with great success.

Lodge Copied Marconi's Use of a Morse Inker in a Second Circuit with a Relay

In 1896, Marconi's apparatus consisted of a receiver apparatus using a relay for a second circuit with a second battery to drive both a Morse inker with tape and an automatic tapper to activate the coherer immediately after the reception of each pulse. In 1894, Lodge's apparatus used the single-circuit Branly receiver consisting of a galvanometer, a battery, and a coherer that was tapped at a rate independently of the rate of received signals.

Lodge did nothing more in the field of wireless telegraphy after his 1894 lectures until he heard of Marconi's work at a British Association meeting in Liverpool on September 21, 1896. Lodge confirmed this himself during his testimony given to an examiner for the British House of Commons on April 23, 1907, when he was asked by the examiner about his activities in wireless apparatus: "Can you tell us what you did in 1894, and what you have done since? As mentioned previously, his response was as follows:

> "In 1894, I gave a couple of demonstrations, one in June at the Royal Institution and one (in August, I think) at Oxford, to the British Association, using Hertz oscillators for transmitting signals, using a Morse key in connection with the sending coil, and a Thomson marine or speaking galvanometer for receiving them—sending the signals from one room to another through walls and so on. I sent them also across the quadrangle of the college at Liverpool; but I applied very small power and did not try for big distances. At that time Dr. Muirhead was struck with its applicability to practical telegraphy, and when in 1896 Sir William Preece told the British Association meeting (as it happened, in my laboratory) at Liverpool that an Italian gentleman (at that time unknown) was interesting the Post Office in a secret box, *I knew practically what the box must contain* [emphasis added], and immediately afterwards (the same day) I showed to a few friends a Morse tape

instrument, very roughly working on that plan."

Lodge claimed that he "knew practically what the box must contain." Of course he did, because he heard Preece say at the meeting on that date: "Signor Marconi has now succeeded in producing electric waves and reflecting them from one parabolic mirror to another one and a-quarter mile distant, the waves falling on a receiving apparatus, *which actuated a relay and produced Morse signals* [emphasis added]. He also heard that "the experiments have been made with crude apparatus and without employing 'any great amount of radiant energy.' " Also, note that Lodge was silent about any activities involving his 1894 apparatus until the meeting of the British Association in September 1896, when he first heard about Marconi's use of a Morse inker to record messages at long distances.

It appeared that Lodge let the matter rest until May 10, 1897, the date he filed a preliminary patent application for a wireless telegraph system. However, the preliminary application stated: "The excitation…at the sending station may cause a *Morse or any other telegraphic instrument to respond at a distant station, by reason of being associated, through a relay or otherwise, with a subsidiary circuit* actuated by electric oscillations… [emphasis added]" These words are virtually the same as the words Preece used to describe Marconi's apparatus at the meeting of the British Association in 1896. The galvanometer that he used in his 1894 apparatus was not mentioned anywhere in his preliminary application, but a Morse inker was mentioned, and it was used as a relay in a second circuit—just like Marconi's apparatus.

On June 16, 1897, after Marconi's apparatus had been revealed by Preece, Alexander Muirhead demonstrated Lodge's first-ever apparatus for radiotelegraphy at an evening soirée of the Royal Institution. This demonstration was reported by a representative of the *Electrician* as follows: "Dr. Alexander Muirhead exhibited an apparatus for performing the same useful operation, 'as practiced by Dr. Oliver Lodge in 1894,' the only addition to *Dr. Lodge's original apparatus being that it was now adapted to a Kelvin ink-writer telegraph* [emphasis added]." It was obvious that Lodge had tested his 1894 apparatus with a galvanometer and discovered it would not work.

On June 17, 1897, the very next day after the soiree, Lodge wrote a letter to *The Times* with the following statement: "I myself showed what was essentially the same plan if signaling in 1894.… My apparatus was substantially the same as now used by Signor Marconi."[127] Obviously, this was not true. Lodge's apparatus was not substantially the same because it did not function as a receiver for telegraphic letters or messages with a galvanometer.

Lodge would later attempt to marginalize the substitution of a Morse inker for his galvanometer by claiming such a substitution was "an obvious one." However, one has to know there is a problem before a solution can become obvious. Since Lodge did not transmit letters in Morse

code in 1894, and there is no evidence that he experimented with radiotelegraphy until after he heard that Marconi had successfully used a Morse inker, it could not possibly have been obvious to Lodge. Clearly, he experimented with his galvanometer much later by attempting to receive Morse code with it and found the galvanometer did not work for registering Morse code. That is when he concluded that Marconi's solution using a Morse inker was a good one.

There was a general belief at that time that the Kelvin galvanometer used as a telegraphic instrument on submarine cables would also work as a telegraphic instrument for wireless telegraphy. Charles S. Bright, a well-known telegraph engineer, was unaware that the Kelvin galvanometer used in marine telegraphy would not work with wireless telegraphy:

> "Yet Prof. Fleming is anxious to claim a technical difference between sending signals and sending a message; and when he talks of Sir Oliver Lodge 'affecting a coherer and so moving the needle of a galvanometer,' he appears to forget that much signaling is done by means of a mirror galvanometer, and that neither Mr. Marconi nor anybody else could claim a monopoly on the grounds of substituting a galvanometer by a Morse recording instrument or a telephone."[128]

Clearly, Mr. Bright did not realize that Lodge's apparatus would not work as a *radiotelegraph* receiver with a Kelvin galvanometer. Marconi's "substitution" made the difference between a radiotelegraph receiver that was capable of deciphering Morse code at a practical word rate and Lodge's galvanometer apparatus that was not. That is the essence of invention.

Lodge Copied Marconi's Antennas in 1898

When Lodge filed the preliminary application for his tuning patent on May 10, 1897, Marconi had not yet confirmed his discovery of Marconi's law. Marconi confirmed this law when he demonstrated the transmission and reception of messages at distances of 5.4 and 14 km across the Bristol Channel with two different antenna heights in May 1897. He demonstrated that the range of his Hertzian telegraph system was proportional to the square of the antenna height. Thus, Lodge had no idea that the height of the antennas on both the transmitter and receiver were critical to the range of early Hertzian telegraph systems at the time he filed his preliminary patent application. That is evident from the wording in his preliminary patent application, which focused on a small dipole or spherical radiator for the transmitter. His preliminary patent application states:

> "The ordinary Hertz vibrator and still more the spheres which I have myself heretofore have employed with a receiving coherer, are powerful radiators, but the vibrations are for this very reason so rapidly damped that no precision of tuning is possible and therefore if such apparatus if employed in a system of telegraphy depending on

Hertzian waves is liable to disturb all receivers within range, instead of an intended selection of them. But if, as in the arrangement I employ in carrying out this invention, the radiator be partially enclosed in a metallic box or cylinder of any shape, or if an arrangement of more electrostatic capacity be employed, then although the radiation becomes less powerful, the total number of swings is so much increased that it may be made as ultimately effective at a distance as the single powerful swing; and it has the advantage of permitting precise tuning or syntonizing, so that any desired one of a number of receivers may be affected."

Lodge proposed to partially enclose his radiator in a box, so he was obviously not thinking about using large antennas that would have radiated long wavelengths. However, by the time Lodge filed his complete specification for UK Patent 11,575 for syntonized radiotelegraphy on February 2, 1898, he proposed to use the two large dipole structures shown in Fig. 20 as the antennas for his new syntonized system. Not only that, but he proposed for the first time to use an antenna of the same height on both the transmitter and receiver and tune them to the same frequency, just as Marconi had proposed in his application for U.S. Patent No. 586,198, filed on December 7, 1896:

"I connect one end of the oscillation producer [source] and one end of the [receiver] circuit closer to earth and the other ends to similar plates [antennas], preferably *electrically tuned with each other* [emphasis added] in the air and insulated from earth."[129]

Marconi described two monopole antennas with one end of the receiver and source connected to earth and the other ends connected to plates on antennas insulated from earth (see Fig. 21). Lodge used dipoles in lieu of monopoles only because he was concerned about infringing on Marconi's British patent, which also specified using two tuned monopole antennas. It is clear that Marconi was the first to document the concept of tuning both the receiver and transmitter antenna

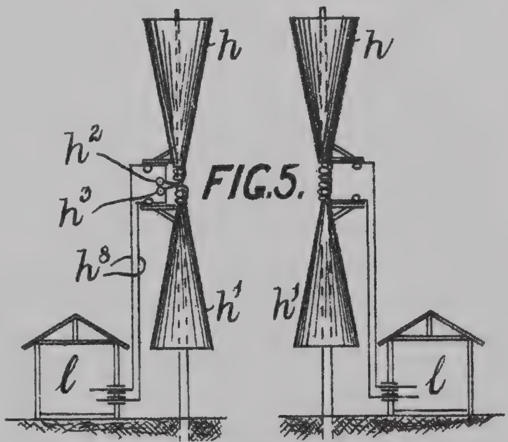


Fig. 20. When Lodge filed the complete specification of his first radiotelegraphy patent on February 1, 1898, he revised the antennas for both his transmitter and receiver circuits by using large dipole structures tuned to the same frequency with vertical polarization, thereby copying the most important features of Marconi's antenna design. (Lodge, UK patent 11,575, figure 5 of complete specification filed February 5, 1898)

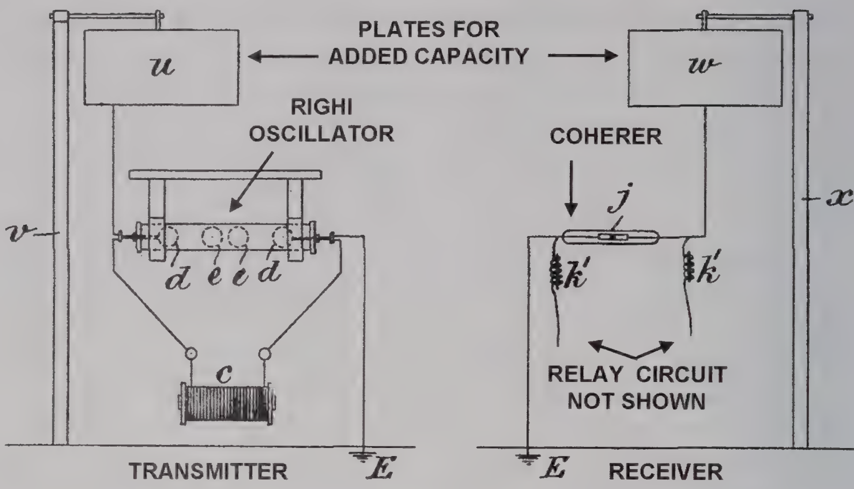


Fig. 21. Marconi was the first to claim that he tuned his apparatus: "I connect one end of the oscillation producer and one end of the circuit closer to earth and the other ends to similar plates, preferably electrically tuned with each other in the air and insulated from earth." (Application for U.S. Patent 586,193 filed on December 7, 1896, p. 1)

circuits to the same frequency—not Oliver Lodge, who first proposed it later in a preliminary patent application filed on May 10, 1897.

Summary and Conclusions

Oliver Lodge invented the history of the invention of radiotelegraphy and documented his version in several publications and especially in his autobiography, *Past Years*, published in 1931. He began with claims that he had discovered electromagnetic radiation independent of and simultaneously with Heinrich Hertz in 1888. He went on to claim that he had discovered the coherer principle in 1889. Finally, he claimed that he transmitted and received letters in Morse code at Oxford in 1894. None of this was true. However, his admirers, mostly British compatriots, were more than happy to believe his claims, despite the lack of supporting documentation and the many obvious inconsistencies in his stories.

Lodge actually admitted that he did not transmit letters or messages in Morse code at hearings in front of an examiner for the British House of Commons on April 23, 1907, but this document went unnoticed by historians until 2013. He also claimed that he did not document his 1894 lecture at Oxford in 1894, but that also turned out to be untrue. He published a description of his 1894 Oxford lecture in the *Electrical Engineer* on August 24, 1894, which also went unnoticed by historians until 2013. There was no mention of a radiotelegraph experiment in his description.

Many admirers to this day believe that Lodge sent and received long and short signals of Hertzian radiation that demonstrated the possibility of wireless telegraph, and also that Marconi's

apparatus was basically the same as the apparatus that Lodge used in 1894. It has been demonstrated in this paper that Kelvin galvanometers of the day were too slow to communicate intelligence by interpreting the dots and dashes of Morse code for practical data rates. Marconi used a completely different receiver circuit using a sensitive high-impedance relay that operated a Morse ink recorder, which he demonstrated could record actual messages at practical data rates in 1896–7.

These admirers also believed that Lodge invented radio by demonstrating transmission and reception of long and short pulses of Hertzian radiation to short distances characteristic of lecture rooms or laboratories, and that there was no need to demonstrate the transmission of messages at practical data rates to practical distances. They also asserted that Lodge knew all the basic principles required to make a practical radio system. However, he did not understand the importance of sending using long monopole antennas on both the transmitter and receiver, and without the two antennas his apparatus was useless for practical applications. It was Marconi who discovered the importance of large antennas of approximately the same height for both the transmitter and receiver, which led to his discovery of Marconi's law. Marconi was the first one to develop a detector capable of transmitting and receiving messages at practical ranges using Hertzian radiation.

Also, Lodge did not understand that the marine galvanometer, which was capable of conveying messages in Morse code using positive and negative signals for dots and dashes of Morse code on marine cables, could not do so for Morse code in wireless telegraphy that required the use of long and short signals. His claim that he demonstrated the possibility of radiotelegraphy with his galvanometer circuit by sending long and short pulses was false because that is not a sufficient condition. It is also necessary to demonstrate that the detector circuit can detect and account for the spaces between long and short pulses, which contain much of the intelligence in Morse code. It was also Marconi who developed the first detector circuit capable of detecting and deciphering messages at practical word rates by also accounting for the spaces between the dots and dashes.

Many historians believed that demonstrating the basic principles was sufficient to award Lodge precedence in the invention of radiotelegraphy. Many also believed that Marconi invented nothing new. Instead, they claim that Lodge demonstrated all the basic principles that were necessary for radiotelegraphy and that Lodge left it to Marconi to take the apparatus he demonstrated and craft an apparatus for practical radiotelegraph applications.

There are five points that many historians have missed:

1. Lodge and the Maxwellians missed one of the most important principles of early radiotelegraphy—the use of tall antennas on both the receiver and transmitter that were tuned to approximately the same wavelength

by virtue of being of approximately equal in height. Marconi's apparatus, which operated on long wavelengths, resulted in a practical telegraphic system with a range proportional to the product of the heights of the two antennas.

2. Lodge claimed that Marconi copied his apparatus, but it was actually Lodge who copied the Hertz dipole radiator for his transmitter and Branly's filing coherer circuit for his receiver. After learning about Marconi's apparatus dating to 1896–7, Lodge then copied Marconi's use of two tall vertically polarized antennas. He also copied Marconi's receiver circuit consisting of a relay and Morse inker with an automatic tapper simulating a self-restoring coherer in lieu of the Kelvin galvanometer and a tapper with a fixed tapping rate set by the time for persistence of the vision of the eye—not the time of arrival of the Hertzian wave pulses representing Morse code.

3. Lodge never demonstrated that his apparatus dating to 1894 was capable of achieving practical distances or practical word rates at any distance. Lodge could have easily demonstrated this at any time in his life if were true, but he never did—and neither has anyone else. In the very first public demonstration of Lodge's radiotelegraphic apparatus at a distance of 100 feet, which occurred after Marconi's patent was published in 1897, it turned out that Lodge had substituted a Morse inker in place of his galvanometer—copying the Morse inker concept that Marconi had been using all along.

4. Marconi's apparatus was not an extension of Lodge's apparatus, which never could have reached practical distances or achieved practical data rates at any distance. It was a radically different apparatus that was copied not only by Lodge but by many other early wireless pioneers, all of whom eventually used two tall vertically-polarized antennas that radiated long wavelengths, and none of whom used a galvanometer to detect and decipher Morse code in practical wireless telegraphy.

5. The definition of invention is something that is new or novel, not obvious, and practical—that is to say, it must have some practical application. There is nothing about Lodge's 1894 apparatus that fits the definition of invention. Lodge, who did not even consider radiotelegraphy before Marconi came on the scene, did not invent, discover, document, or demonstrate a functional or practical radiotelegraphic system prior to Marconi's demonstration at the Bristol Channel on May 13, 1897, when he transmitted wireless electrical messages at practical data rates to a useful range of 14 km, which was much farther than anyone else had achieved before him.

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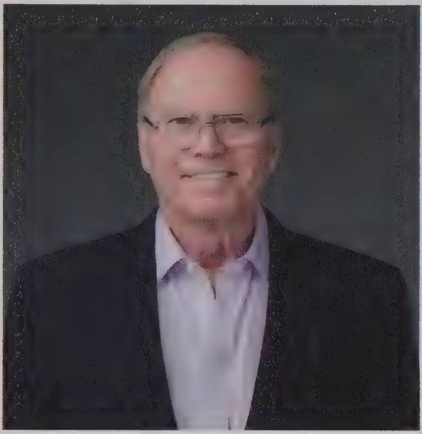


Eric Wenaas

The Simpson Micro-Testers: A Deconstruction of the VOM

The Simpson Electric Company, originally based in Chicago, is well-known for its extensive line of panel meters and probably best known for its legendary Model 260 volt-ohm meter. Yet the company made a wide variety of other products including a long list of test instruments. In the early 1940s, perhaps inspired by one of its main rivals, Simpson released a matched set of thirteen "pocket-sized," dedicated-purpose test meters it called Micro-Testers. Over the next decade it modernized and expand the series. The Micro-Testers sold in vast numbers, and one member of the series (as well as the 260) is still in production today. These instruments are simultaneously collectable and still surprisingly useful. This article explores the origins of the Micro-Testers, and the pocket-sized volt-ohm meters from which they evolved.

Micro-Tester Origins

The volt-ohm meter (VOM)[1] seems like the quintessential piece of test equipment. Small, simple, convenient, portable, and extremely useful—an obvious device most of us take for granted. Yet the VOM took quite a long time, relatively speaking, to take the form we recognize today. It evolved over time from simple panel meters, gradually acquiring additional ranges and functions, but one of its best tricks was being able to slip into your pocket.

Beginning in the 1920s, manufacturers of electronics equipment began to see the value of a single device with which one could make many different measurements—a kind of Swiss Army Knife for electronics. These instruments could measure the essentials—volts, amps, and ohms in various ranges, first only with direct current, but soon with alternating current as well.

As the VOM slowly grew in sophistication, one company, Simpson Electric, originally based in Chicago, hit upon the unorthodox idea that the VOM's usefulness could be greatly expanded by taking it apart. The idea was to offer all the functions of the VOM individually, in separate meters. In doing so, Simpson reasoned it could offer functions and ranges not available in the VOM or that would be difficult or expensive to add. Essentially, the company made a bet that many users, especially those in more arcane industries, did not need

a full VOM. They required only specific functions to suit their specific needs. Such specialized meters, which Simpson would call Micro-Testers, would be less expensive than a VOM, simpler to use, require little or no training to operate, and would be much smaller.

The notion that "small" often carries with it a kind of futuristic sense goes back a long way. Probably no single thing has done more to advance this idea than the transistor, but even in the decades before the transistor, the trend toward miniaturization can be seen. Indeed, the idea of a pocket-sized piece of test equipment carries a lot of appeal. Of course, the concept of "pocket-sized" has changed over time so that during the 1920s, for example, the term might be applied to an electronic device the size of a brick.

When I was ten or eleven, I somehow acquired a Triplett 310 VOM (Fig. 1). I regarded it as the coolest and most modern gizmo I had ever owned. It was hard to imagine anything smaller or better. At the time, I already owned a Heathkit IM-13 VTVM and was well acquainted with measuring stuff. The IM-13 was swell on the bench, but of course, you couldn't put it in your pocket. So I carried my 310—in my pocket—everywhere. At home. At school. On the playground. Everywhere. Just in case I needed to measure something. And measure things I did. Resistors, of course. Various and sundry batteries. Line voltage. Dad's car battery. Daily. Sometimes twice. I measured everything—frequently.

Fig. 1. The Triplett "Mighty Might" VOM Model 310 was introduced in 1956. An almost identical version of this device is still in production today. (eBay screenshot)

The Rise of the VOM

I was reminded of all this one day not so long ago while I was tidying up the shack and found a long-forgotten Weston Model 489 test meter (Fig. 2). It dates from about 1925 and has two DC voltage ranges. (Jewell advertised an instrument in this form-factor in 1923.)[2] This small device cost $13.15 in the day and is what passed for a pocket-sized instrument back then.[3] Meters in this form-factor can be found by at least 1923, and were sometimes referred to as a "table voltmeter."[4]

Digging into my collection of catalogs, I found several other examples from around that time. For instance, the Jewell Model 57 (Fig. 3), from around 1925, looks remarkably like my Weston. And

of special significance is the 1929 Hoyt "Radio Rotary Meter" (Fig. 4), which might be described as a proto VOM.[5]

Beyond these simple meters were so-called set analyzers. They were generally built into clamshell wooden cases, contained one or more meters, and more often than not included the provisions needed to test tubes. The earliest example I could find was the Jewell Radio Model 95 test set (Fig. 5), which appeared around 1925.[6] The Model 95 was an astonishingly expensive device priced at $75, or more than $1,100 when adjusted

Fig. 2. The Weston 489, circa 1925. Derived from simple panel meters, such instruments were what passed for pocket-sized testers. (Author's collection)

Fig. 3. Jewell Model 57, circa 1925. Jewell was an early player in test equipment. (*Van-Ashe Radio* catalog, 1925, p. 36)

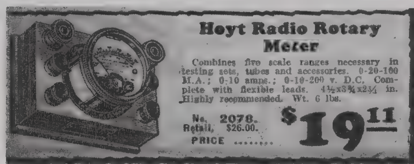


Fig. 4. The Hoyt "Radio Rotary Meter" (no model number given) combined several ranges into a single device that suggests a VOM. The "rotary" nature of the meter is not described in the ad and is not apparent even under close examination. (*Allied Radio* catalog, 1929)

Fig. 5. The Jewell Model 95, 1929. "Set analyzers" performed many of the functions of a VOM, and more often than not included provisions for testing tubes. (*Allied Radio* catalog, 1929, pp. 62–63)

for inflation. With the proliferation of vacuum tubes through the 1920s, such test sets quickly flourished, and by 1929 more than a dozen—in various levels of sophistication and price—were shown in the *Allied Radio* catalog that year.[7]

By 1929 it was easy to find simple, large format test meters in addition to more complex test sets that would measure AC or DC volts, amps, and milliamps; but ohm meters were hard to find. In advertising copy for set testers where specifications were spelled out, none mentions having an ohm meter.

Fig. 6. The Hickok SG-4600, 1930, provided a great deal of functionality, but at a price that put it far beyond the reach of the average experimenter. (*Allied Radio* catalog, 1930, p. 65)

The first example I could find was the Hickok SG-4600 (Fig. 6) set tester from 1930. In addition to volts and milliamps, it had two resistance ranges: 0 to 20 k and 0 to 200 k ohms. Priced at an astronomical $89.18 (nearly $1,500 in 2022), this was not an instrument for the average experimenter.[8] Bear in mind that in 1930 the average family had an annual income of about $2,500.[9]

And of course, the 4600 was decidedly not pocket-sized.

Pocket-Sized

The first VOMs that one might reasonably consider to be pocket-sized appeared in 1929. The Weston Model 564 (Fig. 7) (5½ × 3⅝ × 2⅛) was released that year along with the Jewell Model 574 (Fig. 8) (size not stated, but appears small enough to qualify). The Weston had four DC volt ranges: 0–3, 30, 300, and 600; and two ohms ranges: 0–10 k and 0–100 k ohms. The Jewell measured from 0–300 DC volts and 0–100 k ohms. Both units used multiple jacks to select the ranges, rather than a rotary switch, and significantly, both were actually marketed using the term "volt ohmmeter," though there was no immediate agreement on how to parse the name: "Voltohmmeter" or "Volt-Ohmmeter." And they were not inexpensive, priced at around $500, adjusted for inflation.[10] That's a lot of money, especially so given that America's Great Depression, which began in 1929, was intensifying through this period.

The effects of the Great Depression are clearly evident by comparing the 190-page 1930 *Allied Radio* catalog (probably copyrighted 1929) with its 60-page

Fig. 7. The Weston 564, 1929, one of the very first pocket-sized VOMs, used binding posts to select ranges. (*Allied Radio* catalog, 1931, p. 50)

Fig. 8. Jewell's Model 574, 1929. Small does not necessarily mean inexpensive, as $25.00 works out to about $500 in today's money. (*Allied Radio* catalog, 1931, p. 52)

catalog of 1932 (probably copyrighted 1931). The depression briefly derailed the manufacture and sales of just about all forms of electronic products. Many products, including many set testers, went missing. For example, while Weston's 564 VOM was still listed, Jewell's 574 was not. By 1933, the Weston was also gone from that year's equally thin catalog. Yet by 1934 (probably copyrighted 1933) the industry had regained some of its former momentum.

Allied's catalog that year had grown to 90 pages (still well shy of its former glory), and included the first example of a VOM using a rotary switch for selection of ranges. This unit was made by the International Resistance Company (IRC) (Fig. 9). It used a Westinghouse 1 mA meter and included four DC volt ranges: 0–3, 30, 300, and 600; and three resistance ranges: 0–1 k and 0–100 k ohms, and 0–1 megohm, though this last range required an external battery, so really just two ranges out of the box.[11] The unit, for which no model number was given, sold for a princely $25.50, "weighs only 2½ pounds," and while smallish, it is definitely not pocket-sized. It is interesting to note that in spite of its size, which was clearly in step with the trend toward

Fig. 9. The International Resistance Company's VOM, 1934, was the first example found that incorporated a rotary switch. This obvious improvement would be slow to catch on. (*Allied Radio* catalog, 1934, p. 22)

smaller instruments, IRC's VOM does not appear in any subsequent catalog.

Also of interest in the 1934 catalog was Weston's 665 "Selective Analyzer" (Fig. 10). While certainly not pocket-sized, it is the first example found of a much more sophisticated version of the VOM. The leap forward in this unit is the addition of AC volt ranges and DC milliamperes. Here then, may be the first full-function VOM.[12] This unit uses a rotary switch for range selection and established a design baseline for future VOMs.

By 1935, pocket-sized VOMs had become well-established with no fewer than three such units on the market. These included the Triplet Model 666[13] (Fig. 11), the Ranger 735[14] (Fig. 12), and the Hickok Model 4955[15] (Fig. 13), all of which use rotary switch range selection and include AC and DC scales, as well as ohms and milliamperes.

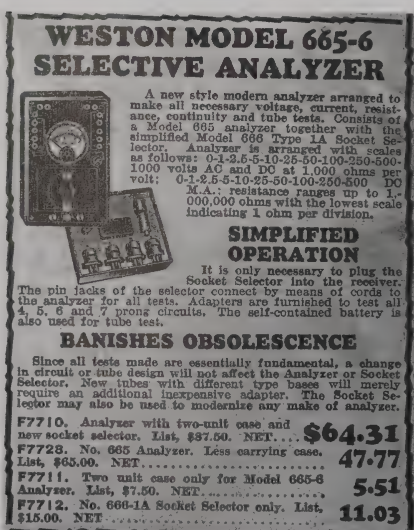


Fig. 10. Weston's 665, 1934, added AC volts and a DC milliamp range, and used a rotary switch. These improvements raised the bar for VOMs. (*Allied Radio* catalog, 1934, p. 30)

Fig. 11. Triplet Model 666. VOMs began to flourish around 1935. These three examples illustrate the "look and feel" of the soon-to-be-modern VOM. (*Radio's Master Encyclopedia*, 1935–36, p. F-6)

Fig. 12. Ranger 735. (*Radio's Master Encyclopedia*, 1935–36, p. F-7)

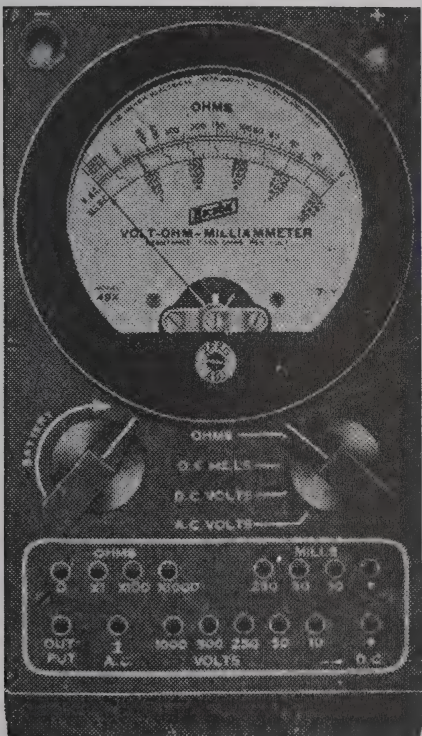


Fig. 13. Hickok Model 4955. (*Radio's Master Encyclopedia*, 1935–36, p. F-38)

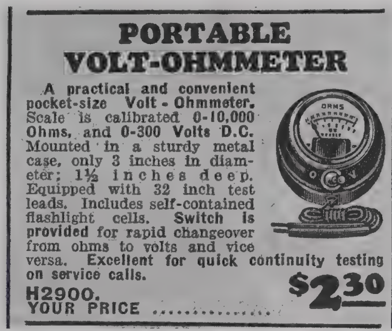


Fig. 14. Readrite—the low cost alternative to a quality VOM. (*Allied Radio* catalog, 1936, p. 28)

Manufacturers of pocket-sized meters rather quickly coalesced around a form-factor of nominally 2 × 3 × 5 inches. Thirty cubic inches, give or take. So, pocket-sized, assuming you had pockets like Captain Kangaroo. These units more or less established a standard for what a compact VOM should look like.

Prices for these instruments ranged from $20 for Ranger's 735 to $80 for the Hickok. Adjusted for inflation, that's from $400 to $1,600. Standing in sharp contrast to these was a tiny portable model from Readrite, selling for just $2.30, or about $45 in today's money (Fig. 14).[16]

There is no official definition of what constitutes a "pocket-sized" device, but for the purposes of this article, I define pocket-sized as a device in which the longest dimension does not exceed six inches. Anything larger may be considered to be "compact," or "portable."

Simpson Electric

In the 1935–36 edition of the *Radio's Master Encyclopedia* (the first edition of the catalog, copyrighted 1936) are two events of special significance to this article. The first is that the Simpson Electric Company made its first appearance. Simpson was incorporated in 1934 or 1936, depending on which section of the company's website you read.[17] A company official I spoke with confirmed that 1936 was the correct date.

In its first ad, Simpson introduced several test equipment products and a series of panel meters. The test equipment line included a tube tester, a radio set tester, and two signal generators, in addition to a pair of VOMs—Models 201 and 202. While the individual pieces of Simpson's test equipment were

nothing special in terms of quality or specifications—though certainly on par with the likes of Weston and Triplett, for example—the company employed what might best be described as a gimmick to set its products apart from the others. All of the meter products used a feature Simpson called Roto Ranger, in which scales for the meters rotated into view on a cylinder located behind the meter movement.[18] Simpson described the Roto-Ranger concept as "revolutionary." Referring specifically to the 201 and 202 VOMs, the company said "… as a result, it is possible to take readings as accurately as if twelve individually calibrated instruments were used." As if reading a meter was somehow complicated. Still, the Roto-Ranger feature (or gimmick) had enough appeal to keep it in the catalog until 1943 (Fig. 15).

The second event is that in 1936 Weston introduced a series of specialized dedicated-purpose test meters sold as "matched test units" in a form-factor similar to the above mentioned VOMs. These include a VOM (Model 564 type 3-C, an updated version of the model introduced

Fig. 15. Introduced in 1936, the Model 201 and Model 202, "Roto Ranger" was Simpson's first foray into VOMs. Compact to be sure, but certainly not pocket-sized. (*Radio's Master Encyclopedia*, © 1936, pp. F-4 to F-42)

in 1931), an output meter (Model 571), a power-output voltmeter (Model 695), a capacity meter (Model 780), and an ohm meter (Model 689).[19] Moreover, they were pocket-sized, measuring nominally 5½ high by 3¾ wide by 2½ deep. However, the 780 capacity meter was AC powered, so that having to stuff the line cord into your pocket disqualifies it as a pocket instrument (Fig. 16).

The idea to create meters for specialized purposes was an interesting one. A marketing conundrum was that while specialized meters are extremely useful, they appeal to a relatively small segment of the electronics market. The rationale seemed to be that trying to include special ranges in a VOM would be impractical and expensive. Splitting these functions into separate products makes them affordable and attractive. Weston appears to have made the calculation that while the market may be small, enough units could be sold to make the series profitable. These instruments may have planted the seeds of Simpson's Micro-Testers.

By 1937, the VOM was commonplace. Most of the major manufacturers offered at least one VOM, though many were larger benchtop or portable units. But the trend toward smaller instruments accelerated in 1937, with a total of nine pocket-type VOMs listed in the *Radio's Master* catalog that year. These included previously issued units from Triplet and Readrite, and also new models from Weston (Fig. 17), and Jackson (with two entries) (Fig. 18).[20]

In the same *Radio's Master* catalog, Simpson Electric followed suit releasing its first pocket-sized model, the 205. "The baby of them all," read the ad copy. While not called a Micro-Tester, the 205 foretold the pattern of the future series, though it is not clear if, in 1937, the company had yet envisioned a whole series of small meters. Unlike

MATCHED TEST UNITS

Model 564
Volt-Ohmmeter Type 3-C

4 Voltage Ranges! 0-3; 0-30; 0-300; 0-600 all at 1000 ohms per volt.
4 Resistance Ranges! 0-1000; 0-10,000; 0-100,000 0-1,000,000 ohms, full scale.
A fine Weston-quality instrument with self-contained 4½ volt battery supplies the necessary potential. Changes in battery potential are compensated for by short-circuiting the resistance pin jacks of any range and adjusting pointer to zero ohms by turning the battery adjustment knob.
Voltage ranges are brought out to pin jacks. Toggle switch connects meter in circuit as a voltmeter, or ohmmeter. A pair of test leads is furnished.
Size: 5⅝" c 3¾" x 2⅝".
Dealer's Net Price, Model 564, Type 3-C **$27.00**

Model 571 Output Meter

This Output Meter is a rectifier type A.C. voltmeter designed for output or volume measurements where a constant impedance type is desired.
Five voltage ranges, 150/60/15/6/1.5, are available at pin-jacks and are selected by a dial switch. A self-contained condenser for blocking any D.C. component is connected to a separate pin-jack. Model 571 has a constant impedance of 4,000 ohms. A long pair of test leads for connection to the speaker voice-coil and an adapter for the output tube socket are provided.
Model 571—Type 3A
Dealer's Wholesale NET Price, $22.50

Model 695
Power-Output Voltmeter

It has a resistance of 2,667 ohms per volt, or 4,000 ohms total on its lowest range and 400,000 ohms total in its highest range. It provides five voltage and eleven dB ranges, selected through a dial switch. —8, —4, 0, 8, 12, 16, 20, 24, 28, 32 dB. 1½, 6, 15, 60, 150 volts. A chart gives corrections for decibel readings on any load from 5 to 50,000 ohms, at 6 milliwatts zero level.

	Dealer's Wholesale NET Price
Model 695—Type 3A	**$27.00**
Model 695—Type 3B (High Speed)	**30.37**

Model 780 Capacity Meter

Model 780 is a newly designed multi-range capacity meter. It is especially suited for measuring capacity of electrolytic as well as paper condensers. Operates from any 115-volt, 60-cycle A.C. outlet.
Ranges: Full scale value—20/2/0.2/.02 mfds. Reads down to .0001 mfd.
Model 780 is equipped with a line voltage adjuster and is insulated from the line by an internal transformer. A pair of long test leads is provided.
Model 780—Dealer's Wholesale New Reduced NET Price........$22.50

Fig. 16. Weston's set of four matching instruments, 1935, was the first example I could find of such a marketing strategy. Their special functions (power output and capacity) were an effort to tap a (presumed) market for more esoteric meters. They are small enough to qualify as pocket-sized. (*Radio's Master Encyclopedia*, © 1936, p. F-2)

Fig. 17. Weston's Model 697, 1937, uses jacks for range selection. At $28 it is considerably more expensive than other models using rotary switches. (*Radio's Master Encyclopedia*, © 1937, p. F-10)

Model 612 A.C-D.C. Multimeter

An excellent general purpose A.C.-D.C. Multimeter. This instrument is very compact and is unusually complete because of its wide range (up to 1000 v. A.C. or D.C.).
Meter—New style square type 3" size. Movement is high quality D'Arsonval type with knife edge pointer.
Ranges—D.C. Volts: 0-10/100/500/1000 at 1000 ohms per V. A.C. Volts: 0 - 20/200/1000. D.C. Milliamperes: 0-10/200. Ohms: 0-500,000. Ohms (Low Scale) 0-500.
Controls—Single main selector switch for all ranges. Ohms zero control.
Case—Welded steel, finished in grey morocco baked enamel.
Dimensions—3¾"x2¾"x6½".
Accessories—Complete with self-contained battery and test prods.
Model 612........ Price **$14.85**

Model 412 New Universal Range—D.C. Multimeter

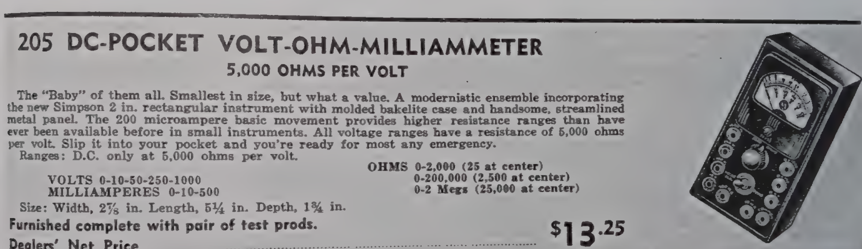
- D.C. Volts: 0-5/0-50/0-500/0-1000.
- 1000 ohms per Volt.
- Ohms: Two scales: ½ ohm to 500 ohms, 200 ohms to 500,000 ohms.
- Milliamperes: 0-1 Ma.
- Special Low Resistance Range—Direct reading.

Sensitive D'Arsonval type in 2¾" Bakelite Case. Knife edged pointer and two colored scale. • Bakelite panel. Phone jacks for standard test prods. Adjustable ohms zero control. Case is sturdy, welded steel 5"x3"x 2" finished in grey morocco. Battery is self-contained within the instrument. • Supplied complete with battery and test prods.
Model 412 Dealer's Net Price Only **$9.85**

Fig. 18. Jackson's relatively low cost meters, 1937. (*Radio's Master Encyclopedia*, © 1937, p. F-15)

Simpson's Roto-Rangers, the DC-only 205 used multiple jacks for selection of ranges, probably in an effort to keep the cost down.[21] It should be noted that the $13.25 price listed was the "dealer net" (wholesale) price. The list price would be nominally twice that—or about $500 today (Fig. 19).

In 1939, Simpson's Model 205 was replaced with the improved Model 235 and was joined by two more VOMs—the 230 and 240. All three of these devices were of the same shape, size, and design. Promoted as the smallest pocket-type instruments on the market, they differed from each other only in the ranges offered. The 240 was referred to as the "Hammeter," with AC and DC volts



205 DC-POCKET VOLT-OHM-MILLIAMMETER
5,000 OHMS PER VOLT

The "Baby" of them all. Smallest in size, but what a value. A modernistic ensemble incorporating the new Simpson 2 in. rectangular instrument with molded bakelite case and handsome, streamlined metal panel. The 200 microampere basic movement provides higher resistance ranges than have ever been available before in small instruments. All voltage ranges have a resistance of 5,000 ohms per volt. Slip it into your pocket and you're ready for most any emergency.
Ranges: D.C. only at 5,000 ohms per volt.

VOLTS 0-10-50-250-1000
MILLIAMPERES 0-10-500

OHMS 0-2,000 (25 at center)
0-200,000 (2,500 at center)
0-2 Megs (25,000 at center)

Size: Width, 2⅞ in. Length, 5¼ in. Depth, 1¾ in.
Furnished complete with pair of test prods.
Dealers' Net Price **$13.25**

Fig. 19. The Simpson 205 VOM, 1937, foreshadows the Micro-Testers, which are still three years in the future. (*Radio's Master* catalog, © 1937, p. F-43)

ranges, DC milliamperes, and ohms. The 230 had slightly different ranges, and the 235 was DC only, but included a microamp range (Fig. 20).[22]

Another instrument from Simpson, the 245 battery tester, was released at the same time. It could test all popular batteries, with or without a load. Without the load, the 245 doubled as a DC voltmeter. The 245 was sold only briefly, perhaps for less than a year. The form-factor of the 230 and 240, combined with the single purpose nature of the 245, set the stage for the Micro-Testers.

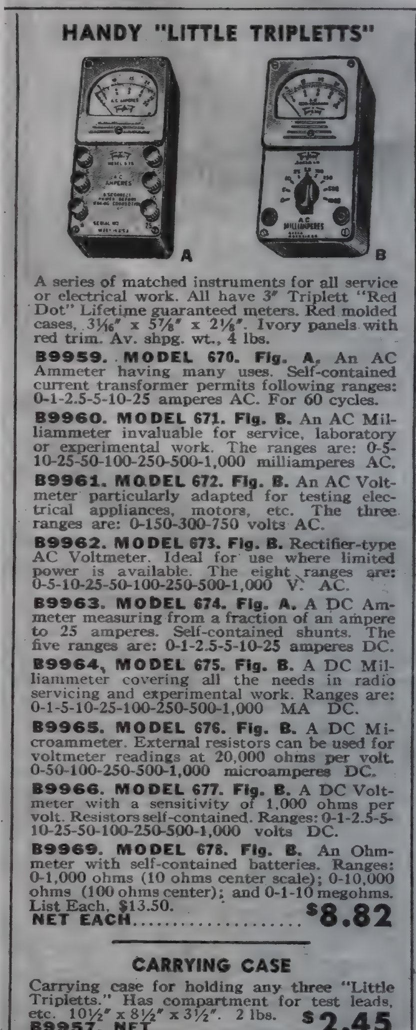
Fig. 20. The year 1939 was a big one for Simpson, in addition to introducing the Model 230, 235, and 240 VOMs, the company unveiled the Model 260, which is still in production today—83 years later. (*Radio's Master* catalog, © 1939, p. F-43)

The Micro-Testers

It's hard to know who thought of it first, but in 1940 Simpson and rival Triplett simultaneously introduced a series of small, dedicated-purpose meters. Triplett called its series "The Little Tripletts" (Models 670–678) (Fig. 21), while Simpson called them "Micro-Testers" (Models 280–288) (Fig. 22). Both series included nine devices with nearly identical functions and ranges. Moreover, both companies' meters were housed in red Bakelite cabinets.[23] The resemblance was striking. Could these matching sets have been the result of industrial espionage? Perhaps that is too fanciful a thought, but the timing and similarity (in both capabilities and design) of the Simpson and Triplett instruments is more than a little curious.

Collectively, Simpson's core group of nine instruments offered 55 ranges of current, voltage, and resistance.[24] Table 1 lists the 280 series of testers and their functions. Taken together with Simpson's previously issued VOMs and battery tester, the Micro-Tester series included 13 products.

In a company brochure, Simpson explained its rationale for the Micro-Testers, writing "Micro-Testers can perform a vital service in industrial plants—in some cases replacing high priced laboratory instruments, in most cases replacing panel instruments used in production testing, and in all cases becoming a handy portable supplement to them." Adding that "the low prices of these Micro-Testers do not mean a sacrifice of quality or accuracy but, rather, serve as proof that Simpson offers today's greatest value in testing instruments."[25]



HANDY "LITTLE TRIPLETTS"

A series of matched instruments for all service or electrical work. All have 3" Triplett "Red Dot" Lifetime guaranteed meters. Red molded cases, 3 1/16" x 5 7/8" x 2 1/8". Ivory panels with red trim. Av. shpg. wt., 4 lbs.

B9959. MODEL 670. Fig. A. An AC Ammeter having many uses. Self-contained current transformer permits following ranges: 0-1-2.5-5-10-25 amperes AC. For 60 cycles.

B9960. MODEL 671. Fig. B. An AC Milliammeter invaluable for service, laboratory or experimental work. The ranges are: 0-5-10-25-50-100-250-500-1,000 milliamperes AC.

B9961. MODEL 672. Fig. B. An AC Voltmeter particularly adapted for testing electrical appliances, motors, etc. The three ranges are: 0-150-300-750 volts AC.

B9962. MODEL 673. Fig. B. Rectifier-type AC Voltmeter. Ideal for use where limited power is available. The eight ranges are: 0-5-10-25-50-100-250-500-1,000 V. AC.

B9963. MODEL 674. Fig. A. A DC Ammeter measuring from a fraction of an ampere to 25 amperes. Self-contained shunts. The five ranges are: 0-1-2.5-5-10-25 amperes DC.

B9964. MODEL 675. Fig. B. A DC Milliammeter covering all the needs in radio servicing and experimental work. Ranges are: 0-1-5-10-25-100-250-500-1,000 MA DC.

B9965. MODEL 676. Fig. B. A DC Microammeter. External resistors can be used for voltmeter readings at 20,000 ohms per volt. 0-50-100-250-500-1,000 microamperes DC.

B9966. MODEL 677. Fig. B. A DC Voltmeter with a sensitivity of 1,000 ohms per volt. Resistors self-contained. Ranges: 0-1-2.5-5-10-25-50-100-250-500-1,000 volts DC.

B9969. MODEL 678. Fig. B. An Ohmmeter with self-contained batteries. Ranges: 0-1,000 ohms (10 ohms center scale); 0-10,000 ohms (100 ohms center); and 0-1-10 megohms. List Each, $13.50.
NET EACH.................. $8.82

CARRYING CASE

Carrying case for holding any three "Little Tripletts." Has compartment for test leads, etc. 10 1/2" x 8 1/2" x 3 1/2". 2 lbs.
B9957. NET.................. $2.45

Fig. 21. The Little Tripletts (shown here) and the Simpson Micro-Testers appeared simultaneously in the 1940 *Radio's Master* catalog. Both series included nine instruments with nearly identical ranges, and both were made in red Bakelite cabinets. (1941 *Radio's Master* catalog)

Fig. 22. The Simpson Micro-Testers. (1941 *Radio's Master* catalog)

Table 1. A comparison of the 280 and 370 series Micro-Testers. (Author)

Original Series	Updated Series	Function
230	230	VOM
235	none	VOM
240	240	VOM ("Hammeter")
245	none	Battery Tester
	362	Low Ohms
280	370	AC Ammeter
281	371	AC Voltmeter
282	372	Ohmmeter
283	373	DC Milliammeter
284	374	DC Microammeter
285	375	DC Ammeter
286	376	AC Voltmeter (rectifier type)
287	377	DC Voltmeter
288	378	AC Milliammeter
	379	Battery Tester
	380	Wavemeter (formerly model 77)
	385	Temperature (–50 to +70°F)
	385-3L	Same as 385 but with 3 probes
	387	Millivoltmeter
	390	AC Volts-Amps-Wattmeter
	391	AC-DC Wattmeter (0-3000 watts)
	392	AC-DC Wattmeter (0-5000 watts)

Each of these diminutive meters measured 2⅞ wide by 5¼ tall by 1¾ deep, and each cost around $10.00 in 1942, or about $170 today (Fig. 23). Each one weighed about 20 ounces and was marked with its model number on the front panel except for the 230, 235, and 240 (Fig. 24). The model number for these meters was engraved on a metal plate affixed to the bottom of the cabinet, and included a caution about measuring high voltages. The plate looked great, but had the unintended consequence of making the meters slightly unstable when sitting upright (Fig. 25).

As noted earlier, the Micro-Testers were housed in red Bakelite cabinets. The meters were red as well, and the front panels were silver-satin metal. The 230, 235, 240, and 245 used black Formica front panels to reduce shock hazard because of their high voltage ranges.[26] Panel markings on the 280 series were screened in black, while the multimeters used gold lettering.[27]

Sometime before 1946, Simpson changed both the red cases and meter to black. Lack of color photos from that period makes it hard to know exactly when the change took place. Other

Fig. 23. The original 280 series (left) used red cases and meters. Later versions (right) used all black components. When the style change occurred is unknown, due to the absence of color photography from the era. Note metal front panels and black screened lettering. (Author's collection).

variations have been noted. For instance, a version with a red meter and a black case was seen on eBay.

Examples of the original red versions are very rarely seen today—even on eBay.

Simpson devoted almost an entire page in describing the Model 240 "Hammeter," arguably the most popular unit of the bunch. The pitch: "The Simpson 'Hammeter' answers the amateur's vital need for a compact, all-purpose tester."

Fig. 24. (Left) This rare early version of the Model 240 provides a splendid example of original red color scheme. Note gold lettering. (Author's collection).

Fig. 25. (Below) The 230, 235, and 240 VOMs were fitted with an engraved metal nameplate on the bottom of the unit. The rivets made the meters a bit unstable when standing upright. (Author's collection).

Adding "…the test cables, for instance, are insulated (to standoff) 5000 volts—a 2000 volt margin of safety." The device uses a copper oxide rectifier for AC ranges.[28] The Hammeter ranges are shown in Table 2.

Table 2. Model 260 "Hammeter" table of ranges. (Author)

Volts AC:	0–15, 150, 750, 3000
Volts DC:	0–15, 75, 300, 750, 3000
Milliamps DC:	0–15, 150, 750
Ohms:	0–3000 (center 30), 0–300,000 (center 3000)
Resistance:	1000 ohms per volt AC and DC

Triplett appears to have abandoned its Little Triplett line in short order, as the last reference to them I could find was in the copyright 1944 issue of the *Radio's Master* catalog. Only the 666 VOM remained, which by this time had evolved into the 666H. The disappearance of the Little Tripletts suggests they could not compete with the Micro-Testers.

Simpson, on the other hand, doubled down on the Micro-Testers, giving the series an update in 1946. In an effort to provide a more modern and polished appearance, the updated units used stylish black Bakelite cabinets with an integrated meter (Fig. 26). The units were renumbered as the 370 series and were a bit taller and deeper than the 280s. Among other changes, the panel legends, which had been screened onto the 280s,

Fig. 26. The new updated Micro-Testers, introduced in 1946, were a bit larger than the originals. The cabinets were now black with an integrated meter and engraved white lettering. The Simpson name was red, but was later changed to white. Left: An old style 240. Right: An updated version of the 230. (Author's collection).

were engraved on the 370s. On this new series, the Simpson name was red, but at some point was changed to white. The 230 and 240 were also updated to match the new 370s, but the model numbers did not change.[29] At the same time, the 235 VOM was deleted, and a new model, the 390 volt-amp-wattmeter was introduced.

The Micro-Testers were advertised as "rugged," and would withstand mild abuse, but were by no means indestructible.

The set was further expanded in 1948 with the addition of the twin-meter 391 and 392 AC-DC wattmeters, occasionally referred to as appliance testers[30] (Fig. 27). And in 1949, the company added the 385 temperature indicator, the 379 battery tester (replacing the long-gone 245) (Fig. 28), and the Model 77 wavemeter.[31] The 385, with its range of

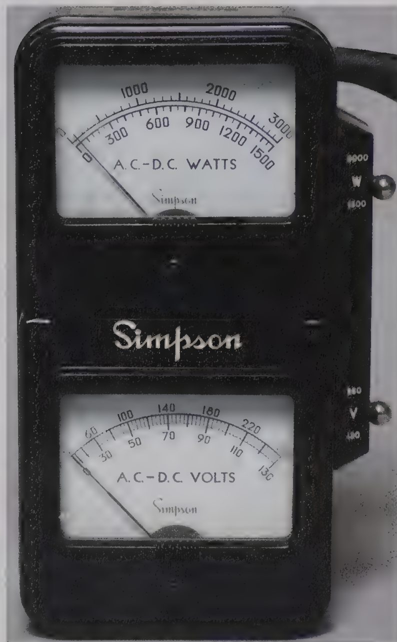


Fig. 27. The 391 wattmeter, 1948. The 392 was visually identical, but measured up to 5,000 watts. (Author's collection).

Fig. 28. Heath's BT-1 (right) battery tester was inspired by Simpson's 379 (left). While the 379 used a rotary switch to select voltages, the BT-1 used a potentiometer. For Heath, it was all about saving a few cents here and there. Saving money was not as high on Simpson's agenda, which focused instead on being the best. (Author's collection).

–50 to +70°F, was designed for use in refrigeration and HVAC work.

The 77 was not originally a member of the Micro-Tester family, though it was the same physical size and shape, but it was renumbered as 380 in 1950, apparently to bring it into the fold (Fig. 29). Two versions of the 380 (formerly Model 77) have been noted. The most obvious difference between them is that the earlier units used plug-in coils with three prongs, while the later version used coils with only two prongs.

After 1949, Simpson took a breather, letting the Micro-Testers ride for a while.

Fig. 29. Simpson's Model 380 wave meter, 1950. While it was the same shape and size as the Micro-Testers, and even shared a series number with them, it was never officially part of the group. (*Radio's Master* catalog, © 1949, pp. F-37, F-41)

In 1954 Simpson changed both the design and definition of "pocket-sized" instruments by introducing an instrument that would actually fit in your pocket—the 355 "Midgetester"—which measured only 4½" high by 2¼" wide by 1" deep[32]— a mere 10 cubic inches as opposed to the 35 cubic inches of the Micro-Testers (Fig. 30, Fig. 31). The 355 was built into a modern plastic (not Bakelite) case and used jacks to select ranges and functions. In a clear sign that the VOM paradigm was shifting, Triplett followed the next year with its own genuinely pocket-sized VOM, the 310 "Mighty Mite," almost identical to the 355 in size and price, but with switch

Fig. 30. Simpson's 355 "Midgetester," 1954, represented a paradigm shift in VOM design. (eBay screenshot.)

Fig. 31. Detail of an ad for the Simpson 355 driving home the point that unlike other "pocket-sized" VOMs, the 355 would actually fit in your pocket. (*Radio's Master* catalog, © 1954, p. G-27)

selection of ranges and functions.[33] The introduction of the 355 would have no *immediate* effect on the Micro-Testers, but bent the arc of the VOM in an entirely new direction.

The Simpson 355 was the first of its kind and fundamentally changed the nature of the pocket-sized VOM. It would take a little time, but eventually almost all manufacturers would copy Simpson's basic design, especially as manufacturing migrated offshore. So successful was this new design that it would survive until at least 1974, after which I was unable to track it further. It is notable, however, that the Triplett 310 is still in production today, 68 years later.[34]

In 1956 Simpson added the 385-3L to the Micro-Tester line (Fig. 32). It was a variant of the 385 that provided switch selection of three temperature probes. The 385 single-probe version was subsequently deleted in 1960. It should be noted that the 385-3L does not have its model number on the front panel like the rest of the series. Variants of the 385-3L

Fig. 32. The 385-3L measured temperature from –50 to +70°F and was used extensively in HVAC and refrigeration service. (Author's collection)

in other temperature ranges and branded for specific customers have been found on eBay (Fig. 33).

The last meters were added to the Micro-Tester series in 1957, with the introduction of the 362 low-ohms meter and the 387 millivoltmeter. The 362 (Fig. 34) was promoted as useful in checking motor armatures and field coils, switch and relay contacts, shorts between generator windings, and so on, while the 387 was designed to check thermocouples.[35]

Fig. 33. Simpson made variations of the 385-3L branded for specific customers. Detail of the 385-3L meter scale (left) compared to a custom version for a customer whose logo I have not been able to identify. (Author's collection)

Fig. 34. The 362 was one of the last Micro-Testers added to the series, bringing the total to 18 instruments. (Author's collection)

And that is pretty much how things remained for the next 30 years or so. Counting only the meters in the catalog after the 370-series update in 1946, there were a total of 18 products in the Micro-Tester series (Fig. 35).

Many of the Micro-Testers received small updates over the years, (designated as a "-2," or "-3" for example) and sometimes more than once. Often, these updates revolved around the replacement of old battery types with modern equivalents.

Micro-Testers were not inexpensive. When introduced in the early 1940s, they were priced at about $10 each, or about $200 today. The 240 VOM cost nearly $14.75, or $300 in today's money. The important point here is that the Micro-Testers, while spendy, were, by design, far less expensive than, for example, Simpson's own Model 260, a full-function VOM, which sold for more than $500 adjusted for inflation.[36] In spite of their cost, the Micro-Testers were immensely popular devices, as evidenced by the fact that most of them remained on the market for nearly 50 years. Not a bad run for any piece of test equipment.

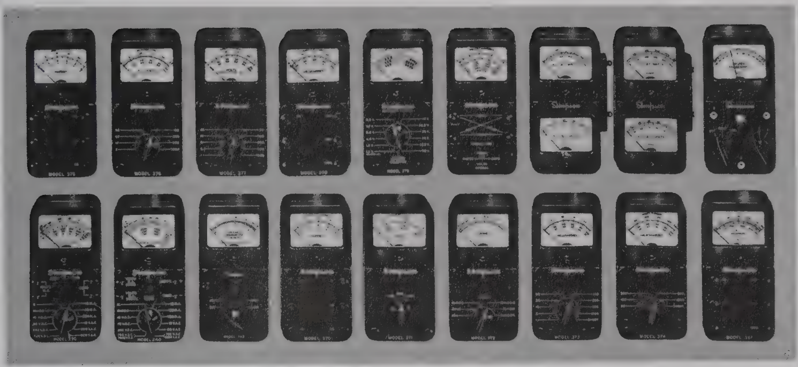


Fig. 35. The Simpson Micro-Tester family. Top row, from left: 375, 376, 377, 378, 379, 390, 391, 392, 385-3L. Bottom row, from left: 230, 240, 382, 370, 371, 372, 373, 374, 387. (Simpson Bulletin 2076, 1967, pp. 10-11)

Time Catches Up

Very few products, especially those related to technology, have had the ability to resist the passage of time as did the Micro-Testers. Like crocodiles, unchanged for millions of years, the little black Bakelite boxes survived for decades untouched by evolution.

Still, to paraphrase Dr. Who, time always wins.

Designed years before the invention of the transistor, over the decades the Micro-Testers became increasingly anachronistic. The inexorable march of time and advancement of technology took their toll on these pocket-sized wonders, and one by one, they began to fade away. In 1996 only 11 of the original set remained. In 2003, the group had shrunk to just four (372, 379, 385-3L, and 390).

And yet…

One of the original Micro-Testers, the 372 ohmmeter, remains in production to this day—hand made in the U.S.A., and essentially unchanged—*76 years* after it first appeared (Fig. 36). Let that soak

Fig. 36. The last man standing, the Model 372 ohmmeter. Seventy six years old and still going strong. (Author's collection)

in for a moment. That is the electronic equivalent of finding a trilobite in your bathtub.

What accounts for this holdout? To find out, I talked with Milt Novak. Milt has been with Simpson for 46 years and has vast first-hand knowledge of the company and its products. Milt told me that the single largest purchasers of the 372 are plumbers and well drillers, both of whom use it to check submersible pumps.

This is a niche market I *never ever* could have guessed, and suggests there were probably dozens of these niches that drove sales of specific Micro-Testers for decades. It also seems to validate Simpson's bet that A) many such specialized markets existed—even if you can't imagine what they might be, and B) these markets were large enough to make them worth pursuing.

The entire premise of Simpson's argument for the Micro-Testers is that in many cases, users do not need or want all the functions and ranges available in a full VOM. They need only that *one piece* of the VOM to make the same kinds of measurements over and over again.

The appeal of the Micro-Testers, beyond their diminutive size, was the availability of specific functions and ranges not supported by other portable instruments of the era. For example, high current measurements could not be made on a simple VOM. Neither could millivolts, watts, or temperature readings. The meter found favor in the lab, for continuous measurements of the same phenomena, for example, and in quality control where specific repeated measurements rule the day. High school and college electronics and physics classes probably used the Micro-Tester instruments in large numbers, and there were likely very specific industrial applications that drove sales of particular models.

Interestingly, when it was first introduced in its current form in 1946, the 372 sold for $22.30.[37] That works out to $321.30 today, adjusted for inflation. But if you actually bought one today it would cost only $241.84.[38] So the 372 is actually less expensive today than it was in 1946. Milt noted that the 372 is still selling very well.

Milt also mentioned that there has been some talk within Simpson about the possibility of reviving the 379 battery tester. The 379 was deleted from the series because many of the batteries it supported (22.5, 45, 67.5, and 90 volts, for example) no longer exist. Still, new batteries are now available and an update of 379 could prove useful. Would it look as retro-cool as the 379? Time will tell.

It is impossible to say how many Micro-Testers were sold, but a clue to their popularity can be found on eBay, where they show up with astonishing regularity. These are not especially rare devices. Just be patient and virtually all of them will show up sooner or later on the auction site. They also appear with some regularity at hamfest swap meets.

In spite of their age, most of the original series are still extremely useful. While electronics have changed dramatically over the decades, volts, amps, and ohms have not. I keep several of the Micro-Testers within arm's reach on my bench, and use the 379 battery tester on a regular basis.

Micro-Testers—living industrial fossils from the mid-century modern age of Bakelite and chicken head knobs. Still useful analog anachronisms in a digital world.

Endnotes

1. In early usage, the term "VOM" was used variously to mean "volt-ohm-milliamp" meter or "volt-ohm meter." In this article I use it to mean volt-ohm meter.
2. *Sears, Roebuck & Co.* radio catalog, 1923.
3. Weston Model 489 Table Voltmeter, Van Ashe Radio, St. Louis, 1925, p. 4.
4. *Sears-Roebuck & Co.* radio catalog, 1923, p. 36.
5. *Allied Radio* catalog, 1929, p. 65. Allied's later catalogs included a copyright bearing the date of the previous year. While early catalogs did not include a copyright date, it may be safely presumed to be copyrighted for the year prior to the year displayed on the cover, in this case, 1928. The difference between the title date and the copyright date is common to many catalogs. Readers should bear this in mind when attempting to date a product by its appearance in a catalog.
6. *Van Ashe Radio* catalog, 1925, p. 37.
7. *Allied Radio* catalog, 1929, pp. 62–63.
8. *Allied Radio* catalog, 1930, p. 65.
9. Daniel Starch, "The Income of the American Family," 1930, https://babel.hathitrust.org/cgi/pt?id=wu.89043221407&view=1up&seq=1.
10. *Allied Radio* catalog, 1931, pp. 50, 52.
11. *Allied Radio* catalog, 1934, p. 22.
12. *Allied Radio* catalog, 1934, p. 30. Note that ad copy for the 665 is written in a way that suggests the unit was probably first offered for sale in the previous year (1933).
13. *Radio's Master Encyclopedia*, 1935–36 (© 1936), p. F-6.
14. *Radio's Master Encyclopedia*, 1935–36, p. F-7.
15. *Radio's Master Encyclopedia*, 1935–36, p. F-38.
16. *Allied Radio* catalog, 1936, p. 28.
17. The "about us" section (https://simpsonelectric.com/about-us/company-overview/) lists 1936, while a "capabilities statement" (https://simpsonelectric.com/wp-content/uploads/File/SE-Capability-Statement.pdf) lists 1934.
18. *Radio's Master Encyclopedia*, © 1936, pp. F-4 to F-42.
19. *Radio's Master Encyclopedia*, © 1936, p. F-2.
20. *Radio's Master Encyclopedia*, © 1937, pp. F-10, F-15.
21. *Radio's Master* catalog, © 1937, p. F-43.
22. *Radio's Master* catalog, © 1939, p. F-43.
23. Both the Triplett and Simpson meters first appeared in the 1941 *Radio's Master* catalog (© 1940).
24. *Simpson factory* catalog number 12, undated.
25. Ibid.
26. Ibid.
27. Ibid.
28. Ibid.
29. "Here they are, the new 1946 Micro-Testers," *Radio's Master* catalog, © 1947, p. F-69.
30. *Radio's Master* catalog, © 1948, p. F-11.
31. *Radio's Master* catalog, © 1949, pp. F-37, F-41.
32. *Radio's Master* catalog, © 1954, p. G-27.
33. The *Radio Electronic Master* catalog (formerly *Radio's Master*), © 1955, p. G-143.
34. The 310 is probably for sale from a number of venues. I found several vendors selling the 310 through eBay.
35. The *Radio Electronic Master* catalog, © 1957, pp. G-359, G-364.
36. *Simpson factory* catalog number 12, undated, pp. 10–13.
37. *Radio's Master* catalog, ©1947, p. F-70.
38. From Newark Electronics: https://www.newark.com/search?st=simpson%20372.

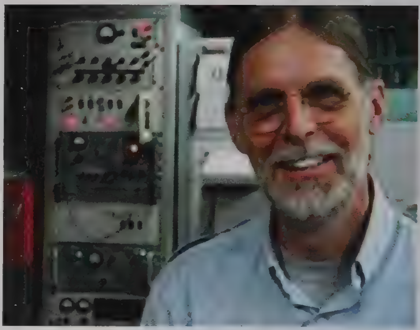
Acknowledgements

My thanks to Lynn Bisha, W2BSN, for his assistance in researching some important data points used for this article. And I would especially like to thank "Uncle" Milt Novak of Simpson Electric for sharing his extraordinary knowledge of the company and its products with me.

About the Author

Chuck Penson is an industrial archeologist and is retired from his position as historian for the Titan Missile Museum south of Tucson, Arizona. Penson has been studying the Heath Company and collecting Heathkits since about 1980. His books include *Heathkit: A Guide*

to the Amateur Radio Products, Heathkit: Test Equipment Products, Heathkit: Hi-Fi and Stereo Products, and *The Titan II Handbook: A Civilians Guide to the Most Powerful ICBM America Ever Built.* Penson's other interests include amateur radio (WA7ZZE), astronomy, geology (with a special interest in radioactive minerals), the intersection of science and popular culture, Cold War history, hiking, and pizza.



Chuck Penson

Listening to the Cradle of Radio: Long Wave Radio Then and Now

Guglielmo Marconi got across the Atlantic in December 1901 on a frequency of about 800 kHz. Then he figured the longer the wavelength, the longer the distance. Soon, spark as a source of radio frequency was replaced by the arc, then by the Alexanderson alternator, then by vacuum tubes. Frequencies got lower and distances longer. Soon radio amateurs discovered that higher frequencies could go further distances with lower power and smaller antennas. Very low frequencies are still, however, best suited for some tasks in the ether. This article discusses many of them, then and now.

I. Radio Came of Age More Than a Century Ago—Growing Up in the Part of the Spectrum We Call the Long Waves—and We Can Still Listen

Guglielmo Marconi ("Bill" to his friends) got across the Atlantic in December 1901 on a frequency of about 800 kHz, or a wavelength of about 400 meters. Then he figured the longer the wavelength, the longer the distance. The idea was that longer waves would sort of walk along the curvature of the earth. Most everyone agreed: e.g., Reginald Fessenden and Karl Braun. So stations went to longer and longer wavelengths at lower and lower frequencies, as low as around 13 kHz, for commercial and naval long-distance circuits. All of these required expensive, high power installations, involving lots of wire for extensive antennas.

Noted radio authority Jack Belrose summarized: "Using 420-foot umbrella top-loaded antennas … tuned to about 88 kHz, [Fessenden] successfully communicated two-ways across the Atlantic in January 1906, between Brant Rock, MA, and Machrihanish, Scotland. Marconi in the meantime had not succeeded in transmitting a complete message, even one way across the Atlantic. Marconi was, however, building bigger antenna systems, and hence moving down in frequency. By 1904, his English antenna had become a pyramidal monopole with umbrella wire, and the frequency was 70 kHz. In 1905 his Canadian antenna, installed at Glace Bay, NS, was a capacitive top-loaded structure, with 200 horizontal radial wires each 1,000 feet long, at a height of 180 feet, and the frequency was 82 kHz."[1]

The higher frequencies, and the shorter wavelengths that are today associated with radio, came into play in the mid-1920s. Long wave radio then died—but it didn't really. The Cradle of Radio is rockin' today.

Radio in today's long wave bands presents, every night, historical resonances, ranging from Marconi to unlicensed amateurs. This episodic history of long wave radio, and its current uses, may provide some insight into these frequencies and these legacy bands. These bands are accessible on modern equipment with simple antennas. And now, despite the ancient (1912) law of only "200 meters and down" for amateur radio operators, they are now once again welcome on the long waves on two licensed bands.

From a historical point of view, one of the most interesting, albeit irregular, signals on long wave is station SAQ in Sweden on 17.2 kHz. It still fires up its 1923 Alexanderson alternator to transmit a few times a year. The VLF Special Interest Group of the California Historical Radio Society continues to pursue this signal as the Holy Grail of long wave radio. (Despite it being very far away!)

In the VLF group, John Staples, Ph.D., W6BM, has focused on WWVB on 60 kHz as a beacon for experimentation, and research into small loop antennas, including the mathematics of loops and resonance. John initially used a Collins R-389 long wave receiver of WWII vintage, and SpectrumLab software to process (and see) the audio output. An image of his equipment appears in Fig. 1.

John Stuart, P.E., KM6QX, implemented a soundcard, SpectrumLab software, and a PC receiver, making

Fig. 1. The VLF receiving post of John Staples on Mt. Shinn, near Lodi, California in 2012, with his Collins R-389 VLF receiver. (John Staples)

a bicycle-wheel diameter and quite an effective loop on a stand. A diagram of his equipment appears in Fig. 2.

Dennis Monticelli, AE6C, provided engineering assistance throughout. Scott Robinson put together one of the VLF group's first working loop antennas. Paul Shinn, K6FRC hosted the 2012 Dxpedition to Mt. Shinn for the group's first try at logging SAQ. Paul had earlier received and verified SAQ. Gilles Vrignaud discovered long wave radio from Europe on the internet by way of remote receivers, for some very interesting broadcast programming and other signals.

My station K6VK used the WinRadio® G33 Software Defined Radio (SDR), and at first a Hustler® 6BTV 33 foot vertical over an extensive ground system, then several iterations of a very large loop, two turns of shielded coax about 50 square meters in capture area, then two 40+ foot tall vertical wire antennas with an impedance-improver circuit from John Staples. The WinRadio SDR provides extensive visualizations of received signals and spectra, by which K6VK first detected the cryptic Russian Alpha radio-navigation stations on 11+, 12+, and 14+ kHz.

Thus, in several ways, long wave signals can be heard *and seen* with today's radios and computers and simple loop or wire antennas—even the Russian "Alpha" stations. See Fig. 3 and Fig. 4.

These long wave signals communicate with submarines and other naval vessels; they aid air and sea navigation; they supplement GPS, and they alert vessels to weather and maritime dangers. A few European long wave broadcasting stations also still vibrate the "ether," although they are almost impossible to hear in California. Radio in today's long wave bands resonates still with historical uses. The long waves (from around 10 kHz to 530 kHz) continue to convey signals from around the world and of local interest. The usual ionospheric variation of propagation of the shorter waves matters little.

A 10 kHz signal has a very long wavelength indeed, some 30,000 meters, or

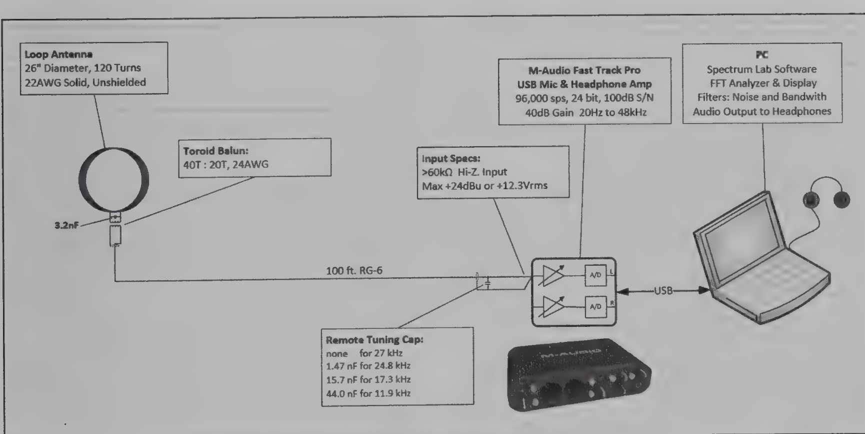


Fig. 2. John Stuart's VLF receiving system, PC-centered. (John Stuart)

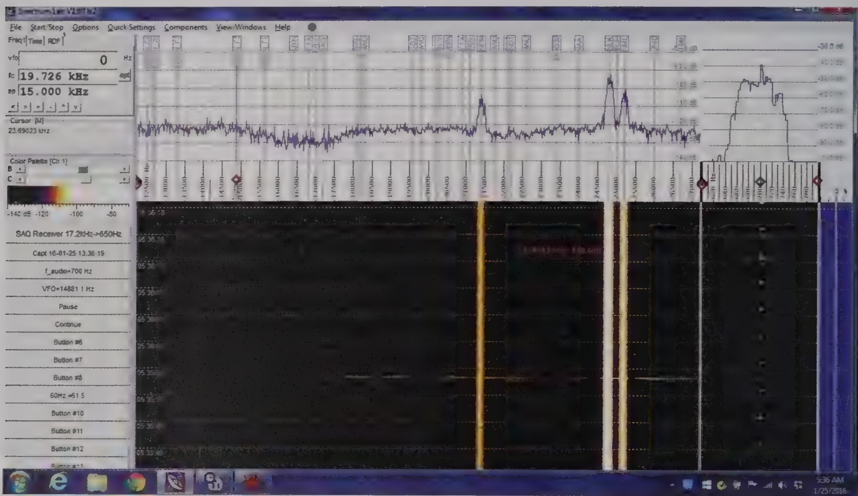


Fig. 3. John Stuart's reception of several VLF stations including a Russian Alpha "RSDN" at 14.881 kHz, its audio on the right using SpectrumLab software. (John Stuart)

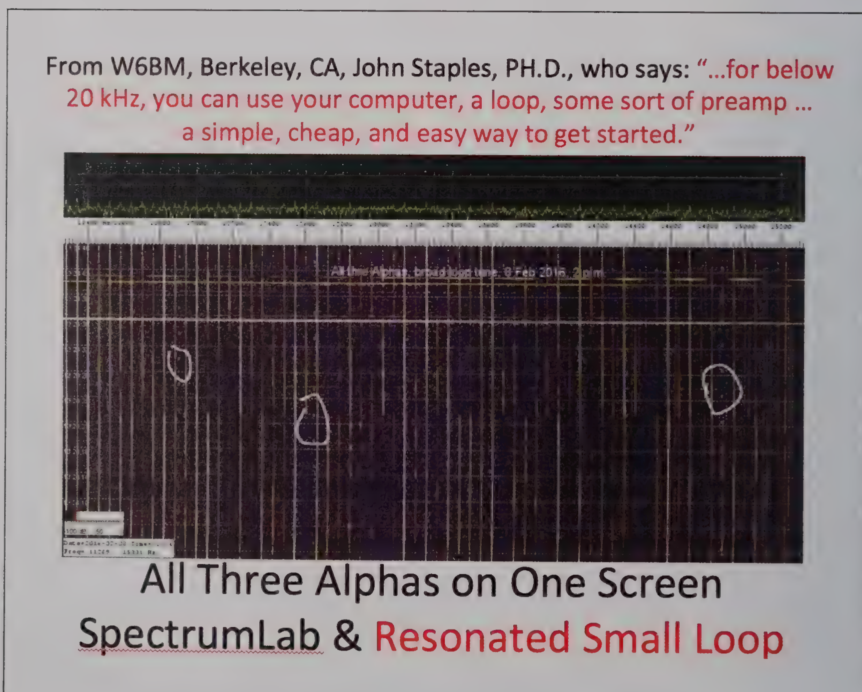


Fig. 4. John Staples' record of receiving three Russian Alpha stations at once using SpectrumLab software and a resonated small loop. (John Staples)

30 km, or about 19 miles. That means that the signal moving at the speed of light is vibrating its electric and magnetic fields at such a rate that it has moved on 19 miles before it returns to the initial states of its electric and magnetic fields (one cycle). By contrast, in the two meter band popular with today's amateur radio operators, at about 146 MHz, the signal moves on only two meters before it reaches its initial field values. In terms of photons, these energy bundles for low frequency radio each carry relatively little energy and hence "vibrate" slowly, at, say, 10 kHz. Conversely, the two meter band photons "vibrate" much faster because they carry more energy at 144 MHz. (The photons of light "vibrate" at 400 to 800 Terahertz). If a 10 kHz signal were audio, some (younger) people could actually hear it.

Despite the wavelength in kilometers, a low-cost up-converter permits a regular shortwave radio to hear these signals; the 0–500 kHz band is up-converted to 3.5–4 MHz (80 meter ham band). An image of such a converter appears in Fig. 5. A loop antenna and soundcard connected to a PC provide both visual and aural reception, especially with audio visualization software such as SpectrumLab. Several software defined radios (SDRs) work well as low as 11 kHz. Many short wave and amateur radio receivers reach down to 100 kHz, or even 30 kHz.

Early radio broadcasters on AM in the 1920s contested the maritime wavelengths, especially 300 meters and 600 meters, or 1 MHz and 500 kHz. Maritime communications settled down to 600 meters, more or less, usually more, i.e., lower frequencies at 500 kHz and below. Maritime services first utilized what we call the long waves, the only wavelengths the equipment of the day could receive or use to transmit. Commercial interests went to longer and longer wavelengths for more and more distance. The U.S. government had banished the radio amateurs to the then considered useless shorter wavelengths, "200

Fig. 5. A commercial VLF converter, where the 0–500 kHz band is up-converted to 3.5–4 MHz (80 meter ham band). Paul Shinn used such a converter to capture SAQ. (Internet sourced)

meters and down" (i.e., 1,500 kHz and up) in 1912.

The "hams" made the best of that challenge within a decade. Almost exactly a century ago, they discovered that communications with wavelengths less than 200 meters, or frequencies above 1,500 kHz, could match the long wave stations for distance (e.g., across the Atlantic). Relatively tiny but sophisticated "homebrew" vacuum tube radios led the way, with the Marconi company and the rest to follow. The professionals had long despised the "hams," but the enthusiastic experimental amateurs had wrong-footed the pros. So, most of what we know today as radio resonates at more than 500 kHz, up to 5 GHz and experimentally much higher.

Looking back a hundred years, that now-ancient wireless telegraphy era from a little after 1900 to about 1922 saw commercial companies, and military and naval forces, adopt the nascent technology. It then worked in the long wave part of the radio spectrum. They drove the technology quickly into a worldwide industry. Although the industry of international communications has flourished for more than a century, the long wave point-to-point technology died very quickly.

The efficiency and lower cost of short wave radio put an end, for example, to most long wave commercial radio point-to-point communications circuits. RCA at "Radio Central" on Long Island, NY, dominated these circuits using Alexanderson GE alternators for European traffic. Only one, however, remains: station SAQ in Sweden. It operates as a museum station several times a year. Both Paul Shinn and Dennis Kidder, W6DQ, have copied SAQ signals in California. In quest of this historical station SAQ, several CHRS members, as a CHRS program, have recently explored many aspects of long wave radio, as the VLF Special Interest Group.

II. The Technologies of Early Long Wave Radio: Sparks, Arcs, Alternators and Then Vacuum Tubes

(A) Sparking Away

In 1901 Marconi used his new Poldhu, Cornwall, UK, station as a pulse transmitter with a double spark circuit. As stations went up in wavelength and down in frequency, the spark employed to emit the radio frequency energy got longer and longer in time as well as higher in amperage. By about 1912, the Marconi stations used large rotary spark gaps to generate an almost (but not quite) continuous wave. A large telegraph key then interrupted this energy with Morse code. The Marconi rotary spark gap in Bolinas, CA, quickly got the nickname "The Rock Crusher" for both the strength of its signal at more than 250 kW and the sound it generated, literally deafening. See the comparable 1914 Marconi Station ZZ rotary spark gap, Fig. 6.

Most wireless communications reached out locally and regionally, at less power. A "quenched gap" spark system could produce a thousand watts (1 kW) or much more. Standard receivers for long waves proliferated. Several companies on the West Coast, such as the early United Wireless Company (and successors) and Federal Telephone

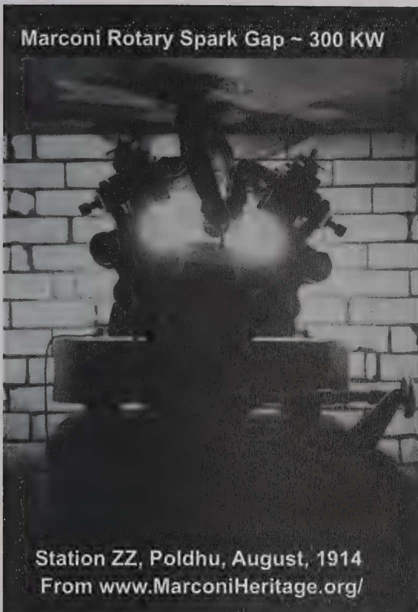


Fig. 6. A Marconi high power rotary spark gap in action August 1914 at 300 kW. (Image from MarconiHeritage.org)

and Telegraph Company, competed for marine and inland traffic, before and after WWI. The Marconi company dominated on the East Coast. An image of a spark station of the era appears in Fig. 7.

(B) Whirling away

The only long wave station that has survived, SAQ in Sweden, still operates its 1922 Alexanderson alternator on 17.2 kHz. An image appears in Fig. 8; the alternator idea originated with Fessenden. At the alternator's heart rotates a five foot by three inch steel disk, spinning at 2,000 rpm. Some 488 brass slots interrupt the magnetic fields around the wheel. These pulses generate the long wave radio frequency energy to be emitted. Alexanderson alternators could reach 100 kHz, but in service ranged around 20 kHz. Power ran upwards of

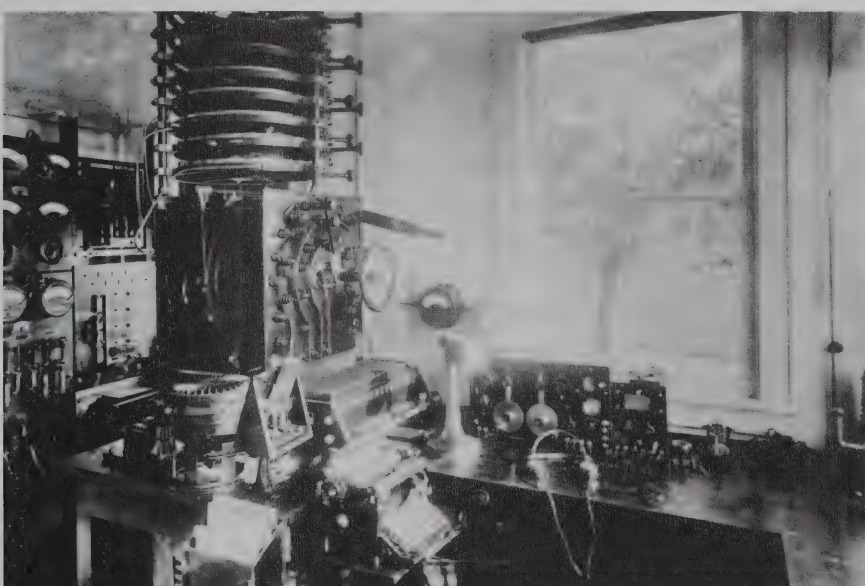
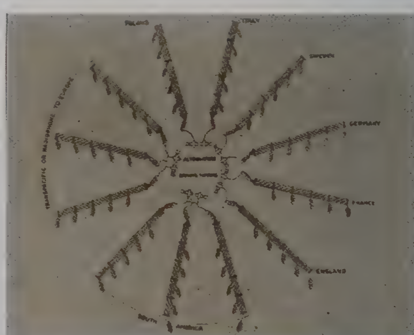


Fig. 7. A spark station, Navy or commercial dating from around WWI. This photo comes from the family of John Staples, and is known only as "Uncle Adrian's Radio Station." (John Staples)

Fig. 8. The alternator at SAQ today. (Bart Lee photo, 2017 at SAQ)

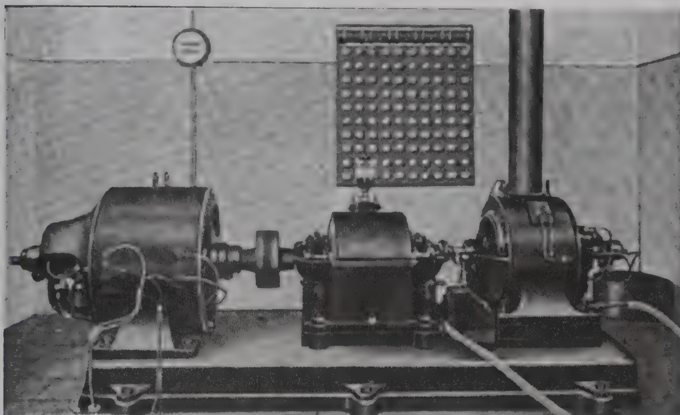
200 kW. Other alternators operated in this frequency range as well. In Bolinas, California, KET (known as "Bolinas High Power") operated at about 23 kHz. Ruins of this station may be seen at the KPH site in Bolinas, maintained by the Maritime Radio Historical Society (MHRS).

The long wave alternator stations required vast antenna arrays to communicate reliably. A series of six radiating high tower vertical antennas (127 meters tall, each with tuned grounds) had to point in the desired direction for each international circuit. RCA laid out its proposed twelve Radio Central arrays in a giant circle on a Long Island property of about ten square miles. The Europe, Japan, and South America circuits each required antenna arrays almost perpendicular to each other. A diagram of the proposal appears in Fig. 9.



RCA Alternator Antennas as Proposed in 1922 for Radio Central on Long Island, NY

Fig. 9. The proposed, circa 1922, antenna arrays for the alternators to be used by RCA for worldwide VLF communications circuits at Radio Central on Long Island, NY.



12.5 kW Goldschmidt alternator installed in 1910 at a wireless station in Eberswald, Germany. It had an output power of 12.5 kW at a frequency of 30 kHz, or 8 to 10 kW at 60 kHz. It consists of a DC electric motor *(left)* driving the alternator *(right)* through a gearbox *(center)* which steps up the rotation speed.

Fig. 10. Goldschmidt alternator installed in 1910 at a wireless station in Eberswalde, Germany. It had an output power of 12.5 kW at a frequency of 30 kHz, or 8 to 10 kW at 60 kHz. It consists of a DC electric motor (left) driving the alternator (right) through a gearbox (center) which steps up the rotation speed.

The German engineer Alfred Goldschmidt developed a similar alternator before WWI, although it operated at lower power. An image appears in Fig. 10. It worked with a frequency multiplier circuit, perhaps as high as 94 kHz.

The Germans put together a worldwide network including Eilvese near Hanover in Germany, at least one station on the U.S. East Coast (Tuckerton, NJ), and at *Lomé*, in the African nation of Togo, then a German colony. Ruins of the Togo station survive, including what may well be the interior disks of a Tesla bladeless disk steam turbine. The British in WWI put a quick end to the German long wave (VLF) network.

(C) Arcing away

Around 1910, Federal Telephone and Telegraph of Palo Alto, CA, put the first commercial arc station on the air from San Francisco's Ocean Beach. Its logo appears in Fig. 11. Oscillations between the arc and the antenna because of the arc's negative resistance generated a continuous wave (albeit with lots of spurious emissions). This too created low

Fig. 11. The logo of Federal Telephone and Telegraph, Palo Alto, California.

frequency, long wave signals. The arc, however, did so with greater efficiency than spark. As early as 1915, the continuous wave arc had shown itself superior to the spark systems.

The arc technology lent itself to very high powers, many multiples of Marconi's biggest spark systems. By 1918, the U.S. Navy had contracted with Federal for two 500 kW arcs for station NSS at Annapolis, MD, for transatlantic service below 17.5 kHz, and for several other shore stations around the world. The navy installed a one megawatt Federal arc in France about 1918 for the other end of the transatlantic circuit. The navy bought many Federal arcs, especially the 30 kW set for ships. History San Jose preserves most of a five kilowatt arc inherited from Federal via the Perham Foundation. A schematic diagram and a drawing appear in Fig. 12 and Fig. 13.

An eight foot tall, 65 ton electromagnet made for a Federal high power arc transmitter sits outside the Lawrence Hall of Science at the University

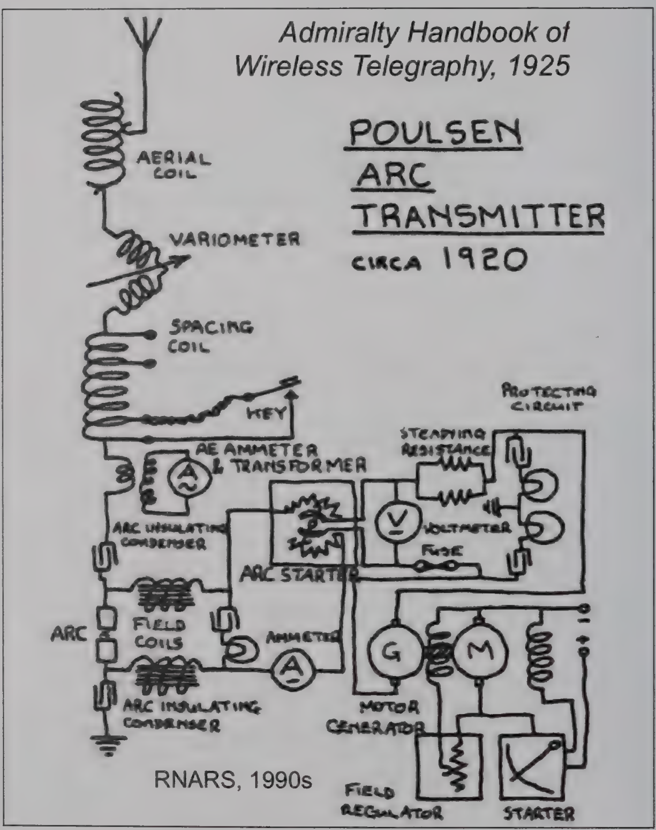


Fig. 12. A schematic diagram of Poulsen arc transmitter, circa 1920. (Cover of a 1994 Royal Navy Amateur Radio Society (RNARS) *Communicator*, 1994; schematic from the *Admiralty Handbook of Wireless Telegraphy*, 1925).

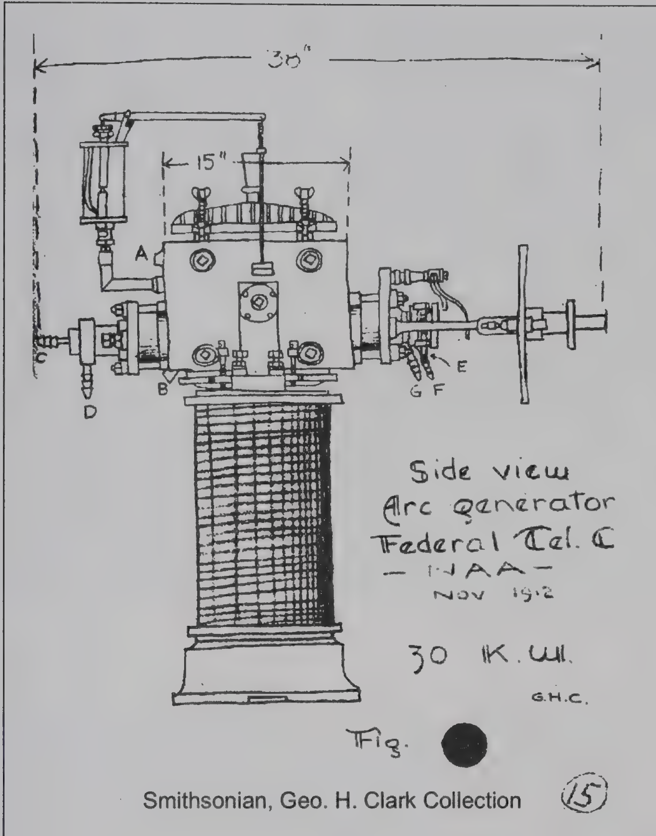


Fig. 13. A drawing by radio historian George H. Clark of a navy 30 kW arc as of 1912. (Smithsonian, Clark Collection, Bart Lee copy)

of California at Berkeley. It once provided a strong magnetic field for Professor Ernest Lawrence's 27 inch cyclotron, as early as 1932. The high power arcs remained in navy service until about 1934. An image of a high power arc appears in Fig. 14. Thereafter the navy used 500 kW vacuum tube transmitters.

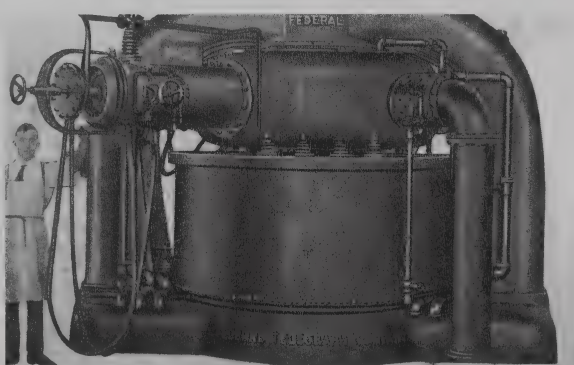


Fig. 14. A one megawatt large Federal arc, circa 1918, which operated in France circa 1920.

(D) Tubes of Nothing

By 1913, Lee de Forest had gotten his little Audion vacuum tube to oscillate at radio frequencies, on behalf of Federal Telephone and Telegraph in Palo Alto. Edwin Howard Armstrong had used the same sort of vacuum tube operation to create the regenerative receiver at about the same time. By 1916, the U.S. Navy used multiple paralleled vacuum tubes, producing a continuous wave that could be modulated by audio, for transoceanic tests of voice transmissions.

Radiomen heard these voice transmissions across the Atlantic in Paris, as intended—but also in Hawaii. Armstrong's regenerative receiving circuit had made worldwide radio possible as of 1914. Vacuum tube transmitters soon replaced all other modes of generation of radio frequency energy, although it took a couple of decades to achieve the high powers of arcs.

III. The Evolution of Effective Techniques for Long Wave Communications

Long wave radio did work long distances. But any transmitter for these wavelengths required massive amounts of electrical power, long lengths of copper-bronze antenna wire in arrays, and an industrial-scale plant. Some of today's working long wave transmitters run at less than a hundred watts (and amateurs are restricted to very low power). But to communicate with U.S. submarines, the navy today operates a network of high power, giant "capacity-hat" antenna digital stations. The mode is Multiple Shift Frequency Keying, MFSK. These stations can range into the megawatts. Their long wave roots go back as far as 1912.

(A) Hearing Long Waves

The U.S. Navy between 1904 and the 1920s learned to use high power long wave radiotelegraph transmitters to reach ships at sea from shore stations. Most early communications with its vessels took place between 175 and 550 kHz. U.S. Navy shore stations used receivers designed to receive down to 10 and 12 kHz. An image of a navy long wave receiving installation, circa the 1930s, appears in Fig. 15.

Of the 36 U.S. Navy receivers listed by naval radio historian Captain L. Howeth[2] as normally used by naval ship and shore stations (excluding direction finder stations) during the period 1912 to 1928, 30 covered the long wave bands, nine of them down to 10 kHz. Two of the earliest were the models A and B, down to 60 kHz and 30 kHz respectively. Two of the latest of the period, the models RAA (for "general service") and the RCC (for "shore stations") went down to 10 kHz and 12 kHz respectively. Long wave radio provided the navy with reliable fleet communications until well after WWII. An image of a WWII-era navy long wave receiver appears in Fig. 16.

A great deal of the progress in the early radio art focused on improving antennas to hear longer wavelengths. One example is Harold Beverage's "wave antenna" for receiving, now known as the "Beverage antenna." One long wire, of at least a wavelength, pointed at the signal source, could gather enough energy for the signal to be heard, while much

Fig. 15. The Navy long wave receiving station in the Washington, DC area, 1930s. (U.S. Navy photo)

Fig. 16. A Navy WWII era long wave receiver. (Internet sourced)

diminishing all energy from other directions, especially noise, thus improving the signal-to-noise ratio.

Loop antennas, picking up the magnetic component of the radio wave, work in proportion to their electrical characteristics and their size—size matters, but not as much as one might expect. Quite small loops can capture VLF signals. On submarines, a loop antenna less than a meter or so wide seems to work just fine, even 15 meters undersea.

(B) Transmitting VLF

Early transmitters (after Marconi's wire arrays) took on a vertical aspect. Instead of horizontal arrays of great length, relatively short vertical elements got the signals out at very low frequencies and emitted very long waves. But they had to resonate at the intended frequency. A vertical antenna has a given inductance, which can be varied (usually at its base; Marconi's "jigger" coil did this). But capacitance to ground also determines resonance.

The vertical long wave antennas, sometimes arrays of vertical elements, got to dress up in "capacity hats." These capacity hats put a lot of wire, sometimes like umbrellas, sometimes as horizontal arrays, above the antenna to form a capacitor to the ground. That added capacitance counteracted the antenna's intrinsic inductance to control the frequency of resonance. The length of the long waves translates to a need for very long antennas for these very long wavelengths, or some shorter antennas "loaded" with extra capacitance, to capture or emit the radio energy. Really long antennas cost a lot, are hard to maintain, and hard to site. Shorter antennas for lower frequencies, however, present challenges because they compromise performance in various ways. Much innovation went into compensation for these challenges.

As early as August 1899, in San Francisco, the experimenters put a large laboratory Ruhmkorff induction spark coil into the *Lightship 70* out in the fog. They wired a "capacity hat"—one of the first—at the top of their vertical wire antenna. Their Morse code signal that the troopship "Sherman is sighted," got through to the Cliff House onshore as the first radio traffic in America. Similarly, Doc Herrold in San Jose around 1916 put a massive capacity hat between buildings at the top of his antennas. He operated an arc transmitter at perhaps 40 kHz. So too, did young William Dubilier in Seattle put an enormous amount of wire atop his very tall antenna in 1909. The experimenters of the day thought that this wire topping did the radiating. Actually the vertical wire "lead," energized by most of the radio frequency current, radiated at the lower frequency of resonance.

By 1918, the radio engineers had managed long wave radio, often using wire arrays above radiating vertical elements. This is still the design of most high power VLF stations.

One history of navy radio in the Pacific[3] reports: "The most important broadcast was the Primary Fleet (FOX) broadcast which was transmitted on the frequency of 26.1 kHz using the 500 kW VLF transmitter at Lualualei. Navy ships at sea and a majority of naval activities

ashore copied the entire FOX broadcast. The Wailupe FOX was the most rapid way to get messages to ships."

The Lualualei transmitter, at 100 kW, came on the air in 1932. The alternator from Bolinas arrived for WWII, so the navy's earlier FOX broadcasts may have gone out on a Federal arc.

On the Atlantic side, Arlington, VA, (call sign NAA) handled the fleet communications. The navy first (in 1913) used a Fessenden 100 kW rotary spark, then a Federal 30 kW arc, then by 1925 a vacuum tube transmitter.[4]

(C) The Short Waves Cometh

WWI both advanced and retarded the development of the radio art. The need for high and reliable traffic volume across the Atlantic locked long wave technology into place, at least for a while. The hope for better radio: cheaper, faster, frequency agile, even portable—drove experimenters to the short waves, above 2 MHz, soon as high as 25 Mhz. These short wavelengths got out fine with way shorter antennas, even as dipole and other fractional wavelength configurations. Amazing (then and now) ionospheric propagation got signals to the antipodes. An early instance, Marconi's Beam Wireless Service, saw short wave signals get from Cornwall, UK, to Australia, as early as 1927. The Beam Wireless signals, at about 9 MHz or 32 meters wavelength, radiated from large vertical parabolic array antennas.

The great short wave revolution in communications drove long wave communications into the dustbin of history by the end of the 1920s. After 1919, the experimenters, amateurs, and professionals like Marconi, even RCA, soon came to see advantages in the higher frequency ranges of what we now think of as the radio spectrum. RCA had planned for many alternators at VLF, with vertical antennas under wire arrays, to cover the world. But by 1923, RCA abandoned the long waves.

Nations soon broadcast directly to each other on shortwave radio by the late 1920s. Armies and navies communicated among themselves and over long distances with relatively small short wave radio systems. After initial success in 1921, amateur radio operators talked across the Atlantic in 1923 on a 110 meter wavelength, and soon to the world on 40 meters and then on 20 meters. The then not-well-understood eleven-year sunspot cycle provided miraculous ionospheric worldwide propagation of radio signals every few years, well enough to maintain various enthusiasms.

Abandoned by RCA, abandoned by Marconi, Telefunken long out of the game, what was left of long wave? As it happens, quite a lot persisted, especially for naval communications, and then more came along.

IV. Long Wave Radio and Nuclear War (Not to Mention Maritime Convenience)

As early as 1918, the U.S. Navy realized that long wave radio could reach its submarines without them having to surface. In WWII, Japanese radar could spot a periscope, but not an underwater trailed antenna. In order to provide safe communications with U.S. vessels

throughout the Pacific, the navy turned to a high power long wave alternator. In its last use, one of the "Bolinas High Power" RCA Alexanderson alternators took up residence in the crater just north of Waikiki, on the Island of Oahu in Hawaii. From there it covered the Pacific theater of wartime operations.

The utility of very long waves, very low frequencies, for communicating with submarines became exponentially more important with the advent of the Polaris class nuclear submarines armed with nuclear weapons (the "Boomer" subs).[5] Both command and control as to launch, and fail-safe to prevent an erroneous launch, came to the fore. Only reliable communications could be trusted to authorize a launch and only reliable communications could prevent a bad launch, likely precipitating full-scale nuclear war by error.

The United States put in place worldwide the 10 kHz to 14 kHz OMEGA stations in the 1970s to provide a reliable fix of position almost anywhere in the world, initially for polar bombers and then for navy vessels. So, too, the Russians created their own Omega-like system (known to us as the Alpha stations), for their own purposes. Both systems featured not direction finding, but "hyperbolic navigation." While this sounds very mathematical (and it is), it's pretty simple at the receiving end. Two curves on the appropriate map intersect at two points, and other information eliminates one of the two. (That other information can be a third related signal). These now 50 year old radio systems pioneered modern "Position, Navigation and Time" (PNT) services. The United States turned off the OMEGA system in 1997 in favor of GPS, the multi-satellite Global Positioning System, for PNT services.

Some of the U.S. OMEGA stations may have converted to submarine communications stations in the range of 15 kHz to 77 kHz. The U.S. Navy and U.S. allies may well have built several of the others from Japan to Europe for this special purpose. At least six such navy VLF stations operate from Australia, Hawaii, the continental United States (three stations), and Puerto Rico.

The question arises: If long waves don't bounce off the upper ionosphere as do short waves, and if ground wave propagation is so limited, how do the signals get around the world? The answer is surprising. The ionospheric D-layer is ionized at night, but of course, not by the sun. These D-layer ions provide the reflective surface (something like a waveguide) that send the long wave signals back down to earth, for the submarines and others. The full-sky energy that sufficiently ionizes the nighttime D-layer for VLF likely comes from cosmic radiation.[6]

Two diagrams of the short day and long night range of the 60 kHz time signal of WWVB, from the National Institutes of Standards and Technology, are shown in Fig. 17 and Fig. 18. So, what may be resonances of the Big Bang (or not), or the results of lesser galactic collisions or stellar bangs, may help to provide some important communications capabilities up to 14 billion years later.

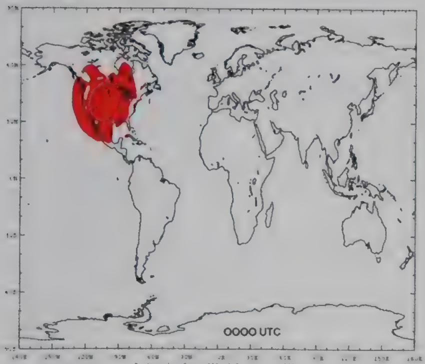


Fig. 17. Day range, WWVB, 60 kHz. (NIST)

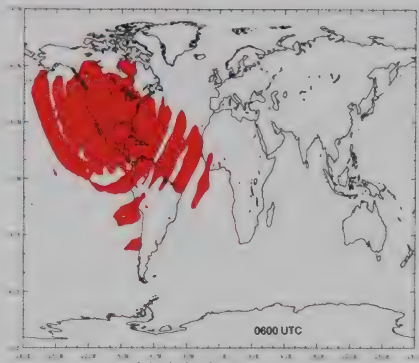


Fig. 18. Night range, WWVB, 60 kHz. (NIST)

Navy VLF stations have used frequency shift radioteletype (FSK) modulation since 1951, and traffic is also encrypted. In California, some of these navy stations are heard and seen all day: e.g., North Dakota, NML (ex-OMEGA); Washington State, NLK; Maine, NAA (honoring the navy's most distinguished old callsign at two megawatts); and Hawaii, NPM. A screen capture of many of the VLF stations as received here, appears in Fig. 19. Others in Australia (NWC) and Puerto Rico (NAU) are night-only catches. They each operate four channels with a total bandwidth of 200 Hz. NATO western Canadian station CKN operates at 76.2 kHz with a wider bandwidth, about 400 Hz.

Russia, China, Japan, and France also operate VLF stations heard in California on winter nights. A map of most known VLF stations appears in Fig. 20.

Russia operates its main worldwide communications network from Moscow

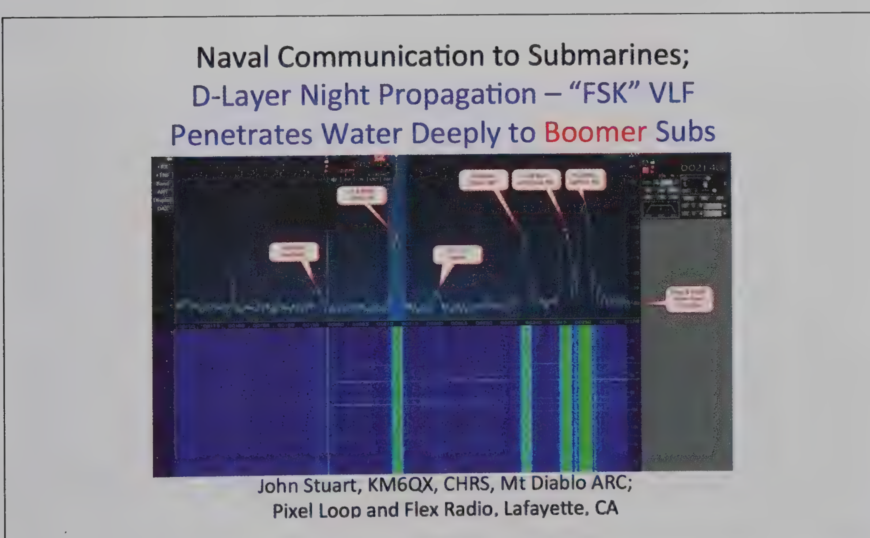


Fig. 19. Some of the more powerful VLF stations seen and heard in California. (John Stuart)

Fig. 20. Most of the VLF stations of the world appear on this map; NPX in Antarctica is perhaps notional.

as RDL on 21.1 kHz, often heard and seen at night. A screen capture of California reception of RDL appears in Fig. 21. The Russians also operate the frequently heard VLF "Beta" data stations and the "Alpha" navigation stations.

Some decades ago, the U.S. Navy operated a transmitter at 76 Hz (a wavelength of about 4,000 kilometers). At this frequency and wavelength, the sea-and-atmosphere interface is just a big waveguide. The capacity of the 76 Hz signal to convey information was limited by its frequency, efficiency, and narrow bandwidth. But that was not its purpose. It was a Fail-Safe. If, but only if, that transmitter went off the air could a submarine launch its ballistic missiles, no matter what other orders it had. Yet that extremely long wave radio system shut down about 1997 (as did OMEGA). The Soviets implemented a similar system at 82 Hz, now long gone also. The British Navy used a similar long wave fail-safe for its nuclear-armed submarines, using the presence of BBC Radio Four on 198 kHz.

The navy has said that its network of VLF stations rendered the 76 Hertz fail-safe station obsolete. Presumably, in the event of war, someone, somewhere, can pull the plug on these stations, just as would have been done on the 76 Hz station. The complexity of the network and its encrypted data would make a spoof impossible, so a false set of signals could not be substituted for the turned-off stations. Russia, on the other hand, seems only to have one around-the-clock worldwide VLF system operating, the navigational (PNT) Alpha stations. Perhaps this is the Russian fail-safe system. Inasmuch as the hyperbolic nature of the positioning is reciprocal, this network cannot be spoofed either. This is so because a submarine navigator would know that the received spoofing signals do not emanate from Russia. Thus, these VLF signals, all of which can be heard and seen in California, may be keeping the world safe.

The Russians broadcast the "Alpha" signals from at least three sites, and at three frequencies between about 12 kHz and 15 kHz. See Fig. 22, a Russian Alpha station. John Staples, as a principal of the VLF Special Interest Group, put the sharp directional null of his homemade loop to work to determine the signals

Fig. 21. The Russian worldwide VLF station RDL on 21.1 kHz, a screencap from the WinRadio G33 at K6VK. (Author's photo)

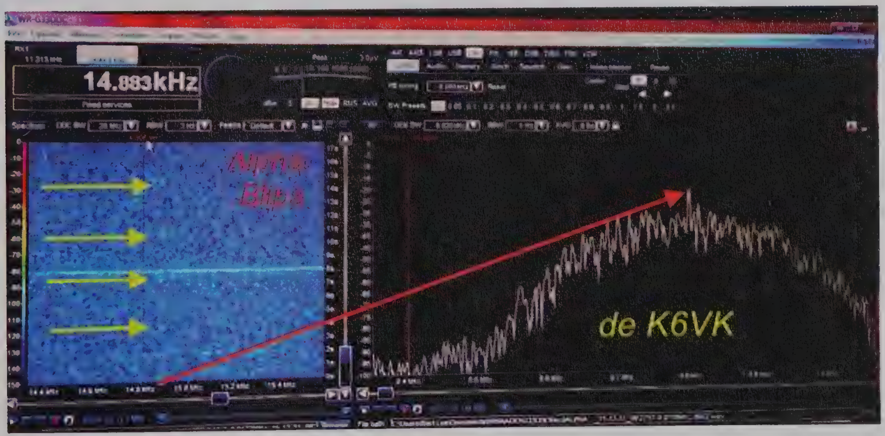


Fig. 22. Audio analysis of the Russian Alpha VLF station at 14.881 kHz on December 31, 2015, at 14:57 UTC at K6VK. (Author's annotated screen cap photo)

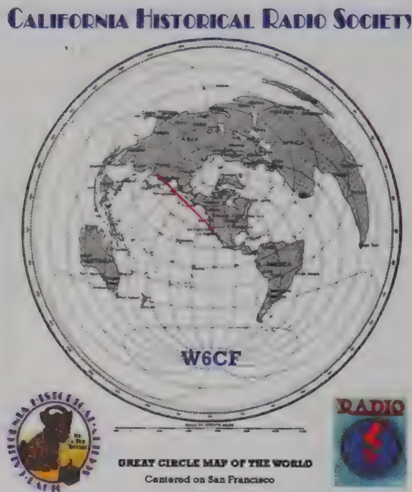


Fig. 23. John Staples' bearing for the Russian Alpha station in Siberia. (Bart Lee and John Staples)

heard here come from the North West. That means the Siberian station North of Beijing. A map appears in Fig. 23.

V. Air and Sea Navigation Aids

Navigation aids developed on long wave, and remained at these frequencies because of long wave's stability. These 24/7 stations are the easiest to hear (and see). From about 200 kHz to over 520 kHz, these airport and shoreside navigational beacons throughout the world for decades sent out two or three letter Morse code identifications (ID) signals, by which aircraft and ships can determine their positions. Only rarely if ever did ionospheric complications ("the night effect") develop for these ground wave systems. Ships at sea could take bearings on shore stations and other ships. Aircraft could determine position by direction finding of airport beacons (as well as city broadcasting stations at considerable range). Coastal and inland stations have long announced themselves with simple two or three letter identifiers, as they do to this day. Until recently, in Northern California, a listener on a radio with a long wave band could hear several of these AM Morse code-identified beacons; for example "CC" at Buchanan Field in Contra Costa County on 335 kHz. An image appears in Fig. 24.

In the 1930s, American console radios often featured a long wave band, as shown in Fig. 25. Yet European long wave broadcast stations rarely got into the American ether. But the aeronautical long wave stations also broadcast AM reports for pilots, around the country. Radio companies made the long wave band a selling feature, like the weather band, in an era when current weather information—and warnings—might otherwise be hard to get.

In winter, stations from Canada to Mexico, and as far east as Montana, mostly in the 200 kHz to 400 kHz range, beeped away into California. The Canadian beacon stations cover considerable distances because they operate at higher power than the U.S. stations. They also send a distinctive "long-dash," and they are still on the air.

The government converted many of the existing or planned long wave transmitters (such as OMEGA and GWEN facilities) into very high power digital beacons in the range of 300 kHz to 400 kHz (but dropped their Morse code identifications). These beacons supplemented the received digital GPS, the

Fig. 24. Station CC in Contra Costa County, CA, at 335 kHz, a typical LF beacon for an airfield. (Author's screen cap)

Fig. 25. The dial showing the "Weather Band" around 250 kHz, on a 1936 RCA 10K console radio. (Author's collection)

Global Positioning System, signals from satellite's. A fixed-position long wave beacon on the ground provided correctional data about GPS satellite signal discrepancies. (The satellite signals are subject to many propagation and other vagaries that limit precision). These ground beacons were operated by the Coast Guard (usually former coastwise beacon sites), the Department of Transportation (one or more of the GWEN sites among others) and in the Mississippi Valley, the U.S. Army Corps of Engineers. A now-dated map appears in Fig. 26.[7] Many of the non-marine DGPS stations are now closed, because GPS-related FAA Wide Area Augmentation System (WAAS) provided by satellites replaced their functions.

After WWII, utilities and governments otherwise continued with long wave radio services for special medium and long distance advantages. United States navigation at sea depended on the powerful Loran stations (LOng RAnge Navigation) operating at around 100 kHz, or 3,000 meters. This too was a hyperbolic system. Loran no longer operates, but a new version, "eLoran" is in the works. This may back up the GPS system, which could be subject to many issues (e.g., bad space weather and malicious interference from Russia). GPS is especially vulnerable in wartime to jamming and spoofing. Tests suggest that eLoran works well even deep inside steel and concrete in the big city, where GPS cannot reach. Its high power signals would be very hard to jam or spoof. Out of concern that their GPS can be spoofed or disabled, the Russians themselves are now returning to long wave Loran equivalents.

VI. Time Signals

Long wave provided reliable time broadcasts. The navy station NAA (from around 1913), as well as the French Eifel Tower station (as early as 1910), sent out time signals for decades on long wave. Two postcards celebrating these stations are shown in Fig. 27 and Fig. 28.

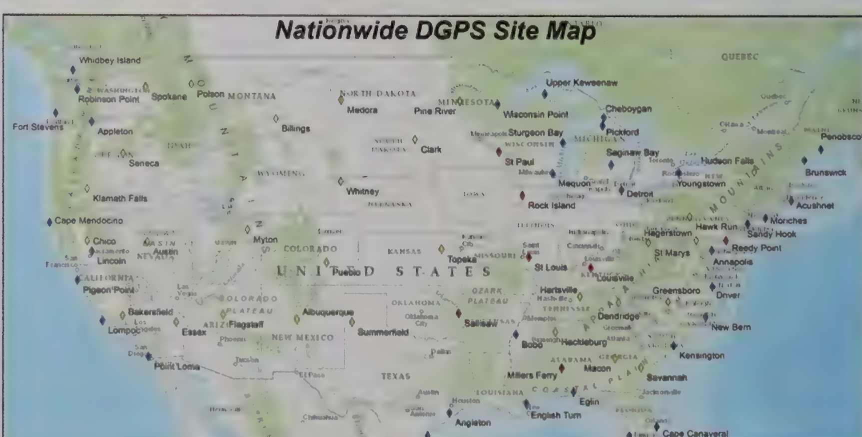


Fig. 26. A map of the late system of the U.S. DGPS high-powered stations. (DGPS)

Fig. 27. Navy station NAA near Washington, DC, on a 1920 postcard; the note says "These broadcast the Arlington time signals." (Author's collection)

Precise timing became a military, naval, scientific, and commercial necessity, especially for longitudinal navigation. Today, several nations operate such time and frequency standard stations, such as WWVB in Colorado on 60 kHz, JJY in Japan on 40 kHz and 60 kHz, and UK station MSF on 60 kHz. A screen capture of such stations regularly heard and seen in California appears in Fig. 29. China transmits time on station BPC, on 68.5 kHz (along with spread-spectrum traffic; this may well be a naval communications station as well, and perhaps a Fail-Safe station). Long wave time signals (e.g., WWVB) are more precise than the short wave ones (e.g., WWV), because of almost no disturbances in the pathways.

The ubiquitous "Atomic Clocks" reset themselves by WWVB at about midnight. SDRs and PC-enabled receivers

Fig. 28. Postcard showing the Paris Eifel Tower, used for radio since 1910, including time signals. (Author's collection)

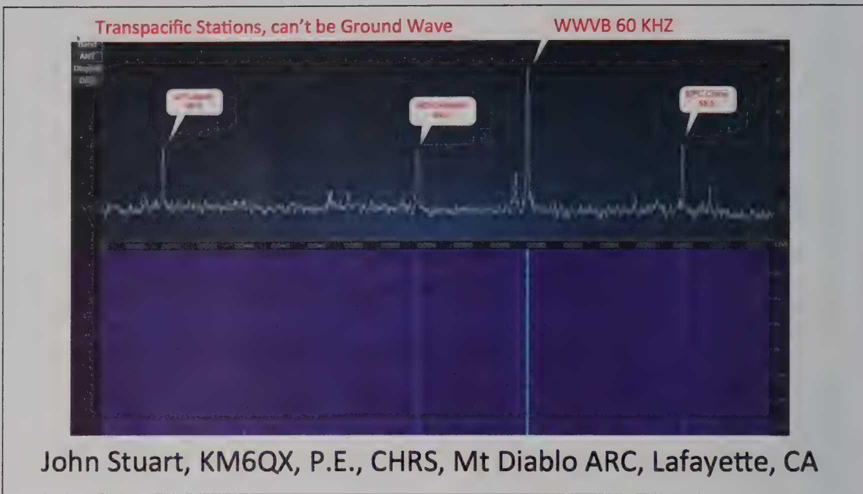


Fig. 29. John Stuart's capture of Asian and U.S. VLF time signals. (John Stuart)

can demodulate and record all of these stations just about every night, at least in winter. A small loop antenna or a longish vertical antenna suffices for WWVB and often for the other stations as well. John Staples has analyzed the WWVB signals in great depth.

VII. Marine Communications

Marine communications continued to use long waves for many decades. The calling frequency remained 500 kHz from the beginning. The frequency of 500 kHz, or 600 meters, permitted vessels' transmitters to operate effectively with relatively short, mostly horizontal antennas, constrained by the length of the vessel. An efficient antenna could make the difference between life and death on the high seas, as well as effect adequate marine communications and minimize received noise. This frequency resonated just below what became the AM broadcast band, but it remained largely the private preserve of the marine and naval shore stations and the ships at sea. These vessels ran relatively low power, other than the naval vessels. Moreover, 600 meters offered the reliability that short wave propagation conditions frequently compromised. Marine communications, however, have now transited through short wave radio and then to satellites.

Until recently, the only marine long wave signals came from the international NAVTEX stations, on 518 kHz. But in the United States, the Coast Guard is soon to stop sending out these regional FSK broadcasts about weather and safety at sea. A second frequency, 490 kHz is in the works and is in use in Europe. San Francisco stations could regularly hear (and demodulate) NAVTEX from as far north as Alaska. Some SDRs provide a NAVTEX software plug-in. An image of a NAVTEX reception appears in Fig. 30.

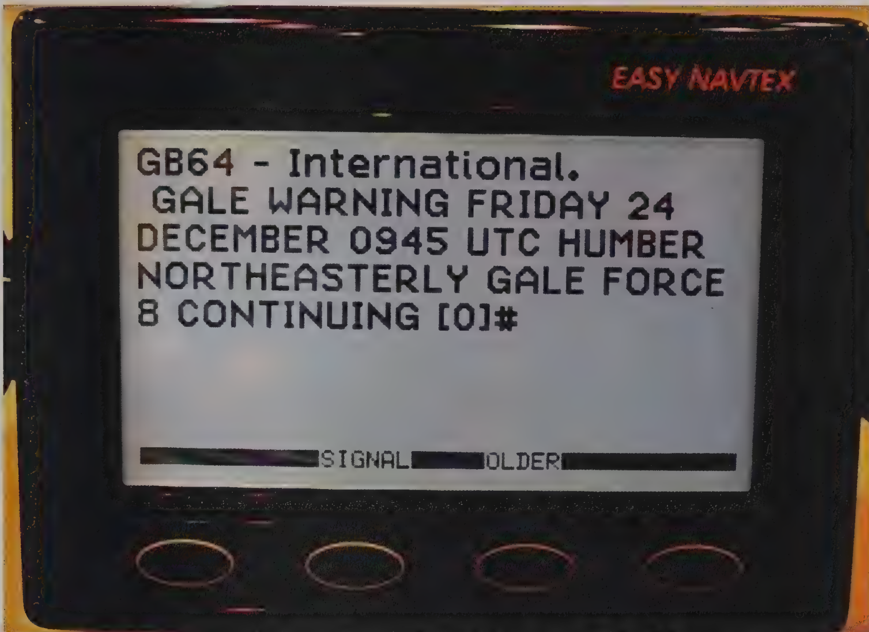


Fig. 30. A NAVTEX reception in England. (Internet sourced)

VIII. National Broadcasting

Broadcasters in Europe from the 1930s on continued to appreciate the stability of long wave signals for listeners, many of whom were too far away for regular AM broadcasting in the new internationally standardized band between 600 kHz and 1500 kHz. Many European countries have maintained AM broadcast facilities on long wave, between 150 and 300 kHz for decades. Some few are still broadcasting long wave to this day. Some commercial stations also appeared in the 1980s. An (old) commercial logo appears in Fig. 31.

These signals escaped ionospheric disturbance, and their listeners heard them by reliable ground-wave propagation. Sure, massive power remained required, often more than a megawatt. But the programs, usually government-sponsored, got through to the people (for better or worse). Some such stations that have been heard in Manitoba, Canada,[8] appear in Table 1.

Fig. 31. The logo of the now-gone long wave broadcaster Atlantic 252; the 252 kHz frequency may still be used for broadcasting. The logo reads "More Music Radio Atlantic 252 Long Wave." (Internet sourced)

Table 1. Frequencies of high-power European stations on long wave that have been heard in Manitoba, Canada.

Frequency, kHz	Station	Location	Power, kW
162	Radio France	Allouis, France	2000
183	Europe 1	Felsberg, Germany	2000
189	Rikisutvarpid	Gufuskalar, Iceland	300
198	Radio 4 UK	Droitwich, England	500

It would be a rare catch to hear one of these stations in California, and then it would only be possible at O'Dark:30 around the winter solstice. Canadian and East Coast enthusiasts do log them, however. A decade ago, Radio Rossi from Siberia reached California on 279 kHz under ideal conditions. Then it went out of business in 2013. A modern UK portable radio featuring the long wave band and the two stations most easily heard appears in Fig. 32.

Gilles Vrignaud of the VLF Special Interest Group has discovered internet long wave radio. With his smartphone, through Wi-Fi and the internet, he can connect to dedicated SDR radios mostly in Europe. They tune in long wave (and other) broadcasting stations. They then make these signals available on the internet.[9]

In the United States, above the 100 kHz range, the Federal Emergency Management Agency's (FEMA) predecessor set out to create a hardened emergency communications network known as GWEN[10] in the 1970s. That acronym came from Ground Wave Emergency Network. It ranged in frequency up to about 200 kHz. Only GWEN WGU-20 on 179 kHz in Maryland got on the air. It opened in 1973 and closed in 1990.

Fig. 32. A modern English "Roberts" portable radio covering long wave as well as AM and FM; note BBC "Radio 4." (Author's collection; radio from the late Alan Carter, BVWS)

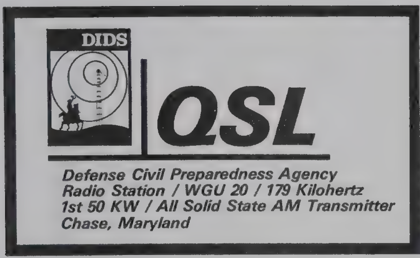
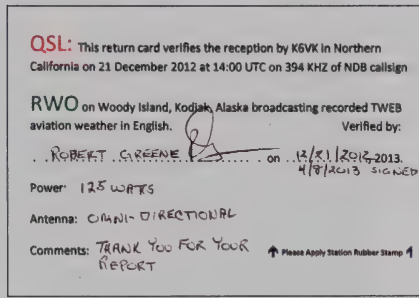


Fig. 33. The QSL card of the only GWEN station to operate, WGU 20, near Washington, DC. The card reads "Defense Civil Preparedness Agency Radio Station / WGU 20 / 179 Kilohertz 1st 50 KW / All Solid State AM Transmitter Chase, Maryland." (Internet sourced)



QSL: This return card verifies the reception by K6VK in Northern California on 21 December 2012 at 14:00 UTC on 394 KHZ of NDB callsign

RWO on Woody Island, Kodiak, Alaska broadcasting recorded TWEB aviation weather in English. Verified by:

ROBERT GREENE .... on 12/31/2012 2013.
4/8/2013 SIGNED

Power: 125 WATTS

Antenna: OMNI-DIRECTIONAL

Comments: THANK YOU FOR YOUR REPORT

Please Apply Station Rubber Stamp

Fig. 34. A "prepared" QSL verification of station RWO in Alaska transmitting voice weather broadcasts, returned to K6VK. (Author's correspondence)

Its QSL card appears in Fig. 33. Much of what the GWEN stations were supposed to do at long wave is now done by the regional NOAA stations on VHF, including emergency notifications, around 162.5 MHz.

Today many cities benefit from low power local-only "emergency broadcast stations" on 530 kHz, just below the broadcast band.

IX. Air Traffic Management

Aviation early took advantage of the stability and the (usually) limited range of low power long wave signals to manage air traffic. Each airport on its unique local frequency provided terminal weather and Notices to Airmen (NAMs) about runways, hazards, and the like. In the San Francisco Bay area, Oakland airport (station WCY) starting in 1929, provided reliable information to airmen, and continued well into the 1970s on 362 kHz. Some home radios, especially consoles and imports, also picked up some long wave in those days. So casual listeners, along with radio amateurs, tuned in as well. Airports in Alaska until recently used long wave for voice Transcribed Weather Broadcasts (TWeB) from the airport beacon stations to report terminal aviation weather. It may be that aurora effects on other wavelengths and frequencies make long wave more reliable that far north. A QSL card for RWO in Alaska on 394 kHz appears in Fig. 34. Today, airports broadcast regular weather and other information locally on AM VHF between 118 MHz and 135 MHz.

X. Long Wave Amateur Radio

For many years, amateur experimenters have been authorized by the Federal Communications Commission (FCC) to transmit unlicensed in the 160 kHz to 190 kHz range, the 1750 meter band, at very low power, less than one watt. These "LowFers" also have occasionally been authorized at higher powers (five watts under Part 5 of the FCC regulations). At least one, WH2XVN (Dave Curry), regularly operated in California on 183.5 kHz. See screen capture shown in Fig. 35.

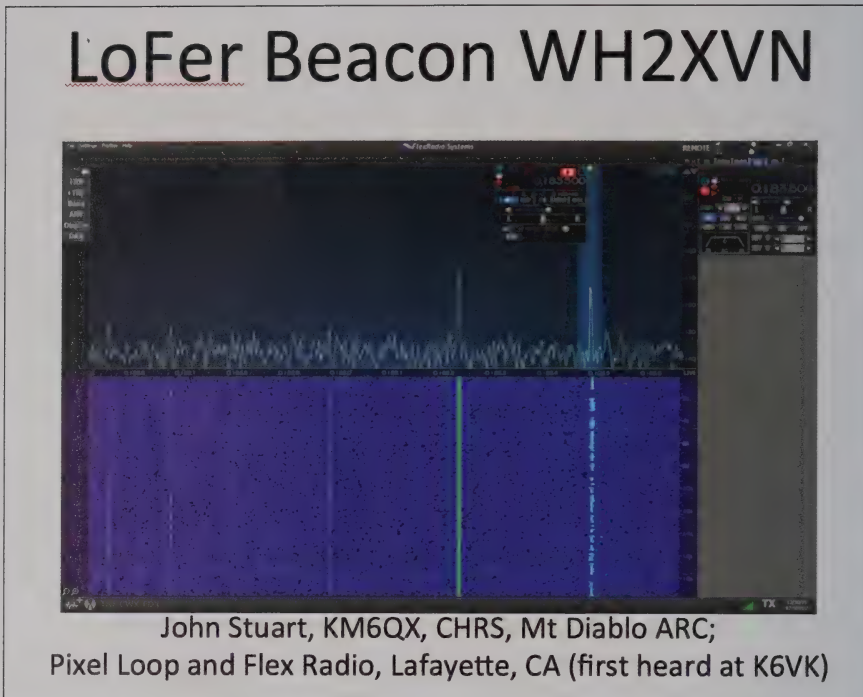


Fig. 35. A record of receiving the Part 5 LoFer beacon WH2XVN on 183.5 kHz. (John Stuart)

At the other end of the power spectrum, the FCC has also authorized marine historical radio in Morse code on the old 600 meter marine frequencies from 425 kHz to 512 kHz. The Maritime Radio Historical Society (MRHS) does so at Bolinas, California. Its principal and Chief Radio Operator is Richard Dillman, whose marine radio "sine" is RD and who is known as "Sparks," amateur radio call sign W6AWO. With the sponsorship of the U.S. National Park Service, MRHS operates KPH/KSM. MRHS has explored these frequencies for several years, with the help of commercial WLO in New Orleans and regional U.S. Coast Guard stations. The Maritime Radio Historical Society seeks to reactivate marine frequencies between 425 kHz and 500 kHz several times a year; see Fig. 36 and Fig. 37. These operations memorialize the great era of long wave marine communications. The operators hold the required commercial FCC First Class Radio-Telegraph licenses. They work their transmit and receive desks as true amateurs, for the love of radio. "Sparks" RD, along with dedicated colleagues, revived and reenact this aspect of radio history (on the short waves as well as long wave).

Starting in 2006, the ARRL operated a 600 meter experimental group as authorized by the FCC under the collective callsign WD2XSH. The ARRL noted over 200,000 hours of

Fig. 36. Morse code from KSM at Bolinas on 426 kHz November 2, 2014, from the WinRadio G33 receiver at K6VK. (Author's screen cap photo)

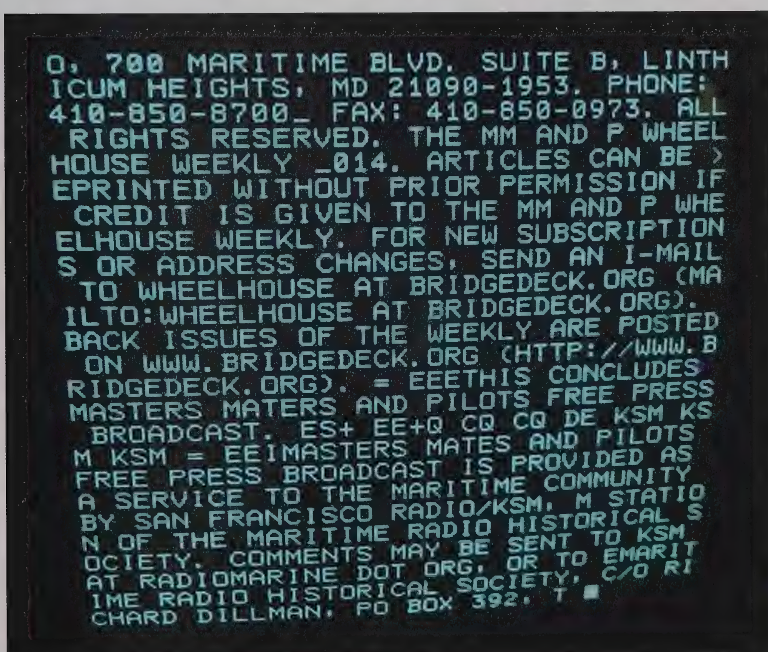


Fig. 37. Readout of the KSM text on 426 kHz November 2, 2014, from the WinRadio G33 by way of the HAL Telereader at K6VK. (Author's screen cap photo)

experimental communications on these frequencies. The 2016 amateur radio Field Day in June featured the operation of a number of the new-pioneering long wave stations,[11] which are shown in Table 2.

The FCC then authorized limited amateur radio activity on the 630 meter band at 472–479 kHz, as well as the 2200 meter band at 136 kHz. (This wavelength was once used for mobile communications by the U.S. Army in France in WWI). These 136 kHz or close frequencies were already in amateur use in Europe and Canada. Joe Craig, VO1NA, got both a 2200 meter signal and an 8 kHz QSSS (slow speed Morse code) signal from Newfoundland across the pond to Europe some years ago. With his very long antenna, he also earlier had acted as the Newfoundland receiving station for the 160 meter Poldhu, UK Marconi beacon experiment of 2006.

Both the 630 meter band and the 2200 meter band are now active amateur radio bands, for WSPR beaconing, Morse code CW, and in Southern California, single sideband voice on 630 meters (according to Dave Curry, a LowFer pioneer). All U.S. states (but one) have enjoyed active long wave amateur communications. Some 21 California stations have activated, and some 180 altogether (according to Ralph Wallio, WØRPK / WD2XSH/34).

Table 2. Callsigns of low power amateur radio stations communicating on long wave frequencies during the amateur radio Field Day in June of 2016.

Callsign	State	Frequency, kHz	Mode	Power, watts
WG2XIQ	TX	474.5	CW	5-7
WG2XSV	WA	475.5	CW	1
WH2XAR	AZ	474.9	CW	½
WD2XSH	WA	475.7	WSPR	
VE7CNF	BC	477.5	CW	2
VO1MRC [VO1NA]	NL	477.7	CW	2

XI. A Mystery VLF Signal Identified

Surprises often appear on long wave bands, especially the very low frequencies. Now these wavelengths mostly communicate from land to deeply submerged submarines. In 2019 a BIG signal appeared "out-of-nowhere" in the long wave VLF band. A SDR full screen capture shown in Fig. 38 of the WinRadio G33 shows the signal. At about 22.7 kHz and with an 800 Hz bandwidth, it does not come from any of the operating U.S. Navy VLF land station transmitters (four of which appear in the screenshot).

The navy has for many years standardized its submarine communications at a 200 Hz bandwidth, MFSK (Multiple Frequency Shift Keying), with multiple carrier frequencies sometimes seen. There is no listed or observed navy VLF land station signal at more than 200 Hz bandwidth. One aeronautical signal is, however, listed: the U.S. Navy airborne TACAMO system at the observed 800 Hz bandwidth: "00022.6:unid:US NAVY TACAMO mobile worldwide, F1B-50Hz/190Hz/MSK 400Hz/800Hz BW. TACAMO is an acronym for TAke Charge And Move Out."[12]

The navy has operated TACAMO for several decades, since 1962. The wiki says: "TACAMO (Take Charge And Move

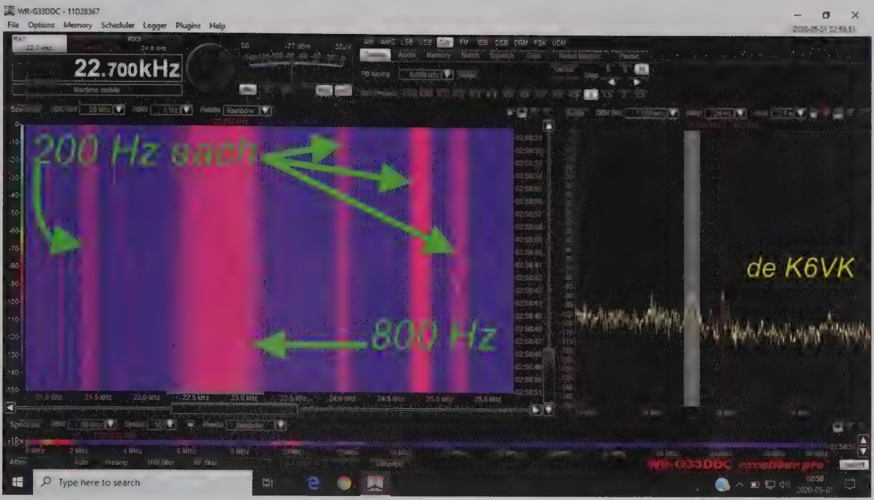


Fig. 38. A strong (32 microvolt), 800 Hz bandwidth MFSK VLF signal appeared at 22.7 kHz on May 1, 2020 at about 03:00 UTC, early evening local time, on the WinRadio G33 using a Very Large Folded Loop antenna. (Author's screen cap)

Out) is a United States military system of survivable communications links designed to be used in nuclear warfare to maintain communications between the decision makers (the National Command Authority) and the triad of strategic nuclear weapon delivery systems. Its primary mission is to serve as a signals relay, where it receives orders from a command plane such as Operation Looking Glass, and verifies and retransmits their Emergency Action Messages (EAMs) to U.S. strategic forces. As it is a dedicated communications post, it features the ability to communicate on virtually every radio frequency band from very low frequency (VLF) up through super high frequency (SHF) using a variety of modulations, encryptions, and networks, minimizing the likelihood that an emergency message will be jammed by the enemy."[13]

The wiki adds that "a west coast alert base at Travis AFB, California" near Sacramento, hosts some of the operating aircraft. So, too, other sources.[14] *Popular Mechanics*[15] recently ran an article titled: "This Unarmed Plane Is the Deadliest in the U.S Arsenal. The E-6 Mercury doesn't carry any weapons, but it could end civilization as we know it."

A Russian website conveniently collects some 20 of the TACAMO VLF frequencies from 19.7 kHz to 29.6 kHz.[16] Other sources also list 27 kHz.[17]

Each TACAMO aircraft, (in this case an E-6 "Mercury"— a modified Boeing 707, in December 2019) flies a unique spiral pattern (Fig. 39) above the sea, with a 200 kilowatt VLF transmitter.

This aeronautical event was reported in *The War Zone*,[18] titled "Here's Why An E-6B Doomsday Plane Was Flying Tight Circles Off The Jersey Shore Today." Part

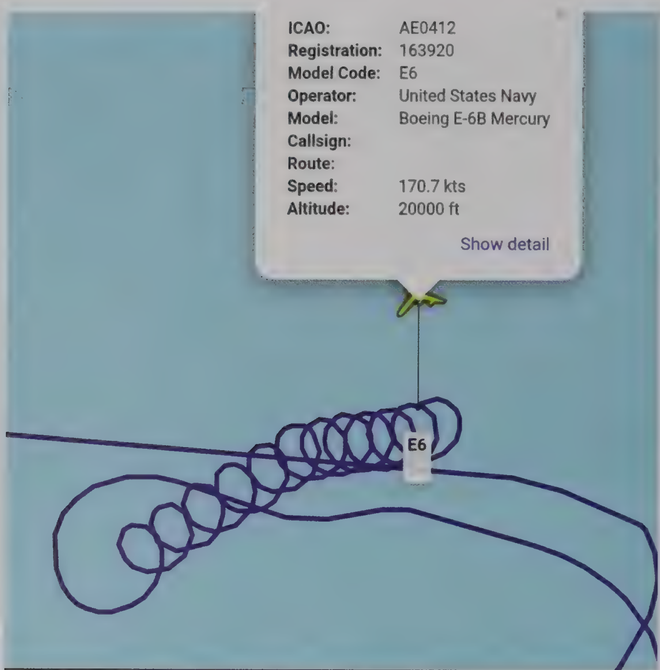


Fig. 39. As plane-spotting goes, this is as good as it gets; this diagram with data was posted by "Evergreen Intel @vcdgf555" on Twitter on December 12, 2019. The note reads "ICAO: AE0412, Registration: 163920, Model Code: E6, Operator: United States Navy, Model: Boeing E-6B Mercury, Callsign: (blank), Route: (blank), Speed: 170.7 kts , Altitude: 20000 ft. (Evergreen Intel @vcdgf555)

of the E-6B's critical mission is to fly aerobatic-like maneuvers that allow them to send messages to ballistic missile submarines hiding below.

The article reports: "The E-6B's primary VLF antenna is just over five miles long. It also has a shorter one that is deployed via a trapdoor arrangement in its tail. The VLF antennas are stabilized with a drogue on its trailing end. The idea is to get the antennas as close to vertical as possible for maximum transmission effectiveness. This is done by putting the aircraft into a very steep and tight banking turn at a slow speed and above 20,000 feet, not far above the aircraft's stall speed. These turns are repeated, oftentimes for hours at a time, as messages are sent."

Given the strength of the signals received here in the San Francisco Bay Area, the transmitter likely flew just off the West Coast. The observed signals often (but not always) seem to end at about 03:00 UTC.[19]

Almost all VLF transmissions, by our navy and other countries, are long range and strategic in nature. The VLF TACAMO system, on the other hand, is tactical. An alphanumeric single sideband voiced Emergency Action Message, as heard for years as "Sky King" on HF

Air Force frequencies, is relatively short. As data, it would be minuscule. But the MFSK bandwidth of 800 Hz suggests a great deal of digital data going down to one or more submarines. This is likely not email for sailors. It may well be a drill (or not) of retargeting data for the Boomer subs. Sometimes a much narrower signal appears; in this case several minutes before the wide signal; see Fig. 37.

The nearby navy MFSK stations at 200 Hz bandwidth, for comparison, are shown in Table 3. Note the 2.6 kHz gap between the navy's NPM and NAA center frequencies. This leaves plenty of bandwidth into which the navy can slot an 800 Hz wide MFSK signal if needed.[20] No intentional interference from any foreign land station is likely because of the difficulty of retuning VLF transmitters.

Table 3. Navy MFSK stations operating at 200 Hz bandwidth.

Station	Frequency (kHz)	Location
NPM	21.4	Lualualei, Hawaii
NAA	24.0	Cutler, Maine
NLK	24.8	Seattle, Washington
NML	25.2	LaMoure, N. Dakota

Sometimes this signal appears with perhaps two internal carrier frequencies (see the screen capture graphic of Fig. 40), at time 02:41:31. The signal approximates a 100 Hz bandwidth. TACAMO has been listed at sometimes 50 Hz and 190 Hz bandwidths in F1B modulation. F1B is frequency modulation, one channel, radioteletype or digital. Perhaps this

Fig. 40. This initial 22.7 kHz signal's bandwidth may be 100+ Hz, early in the evening of May 1, 2020. This signal is stronger than NLK in Washington state ("Jim Creek") at 24.8 kHz, bandwidth 200 Hz. (Author's screen cap)

trace shows two such signals in parallel. Shortly after this capture, the signal ended and then came up at 800 Hz bandwidth, as shown in Fig. 41.

Available receiving antennas can provide some directionality. The paired verticals at 40+ feet high at K6VK are omnidirectional. Their signals appear at the top of the next capture, Fig. 42.

The next level down is a large, single wire loop about an average 10 feet high and 120+ feet long, in an "L", first North/

Fig. 41. The signal's bandwidth grows to 800 Hz with two internal carriers at 02:44 UTC. (Author's screen cap)

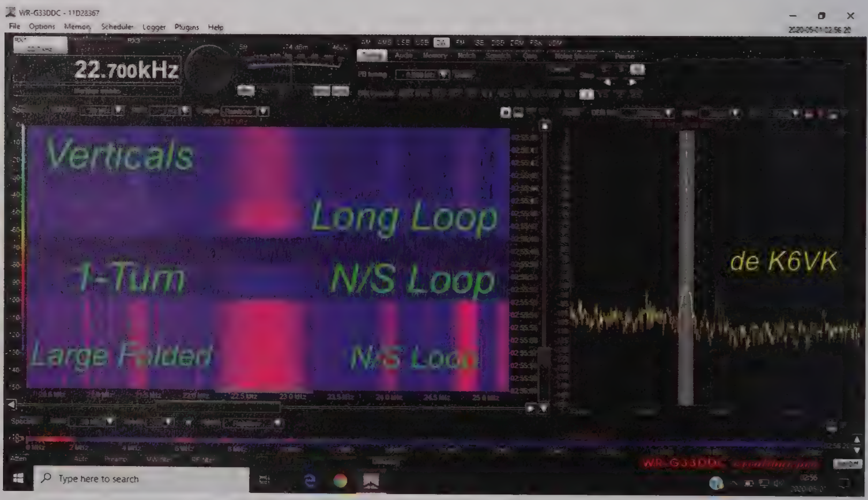


Fig. 42. The signal on 22.7 kHz at 02:56 UTC by way of four differentially directional antennas, the north-south VLFL loop was strongest at 46 microvolts on the WinRadio G33 at K6VK. (Author's screen cap)

South then East/West. It returns the strongest signals from the West. In this case, the signal is stronger than that received by the verticals. The North and East stations are weaker than on the verticals. Hawaii NPM is about the same strength. The third level down is a single turn (somewhat kinked) copper pipe large loop. It receives the best North/South. Only the 22.7 kHz signal appears. The lower band is a multiturn Very Large Folded Loop. It sees the 22.7 kHz signal as strongest (at 46 microvolts and -74 dBm) and NLK Jim Creek is comparable (and due North). One can infer from this rough data that this signal comes roughly from the North.

The signal of Fig. 43 was first observed at K6VK in November 2019. Its strength was comparable to NPM in Hawaii. Perhaps the aircraft then flew in that area. The aircraft usually fly at least at 20,000 feet altitude and NPM is not much above sea level.

The navy has hardened the TACAMO aircraft (Fig. 44) against nuclear blast and atomic-bomb-created electromagnetic pulse radiation (EMP). In

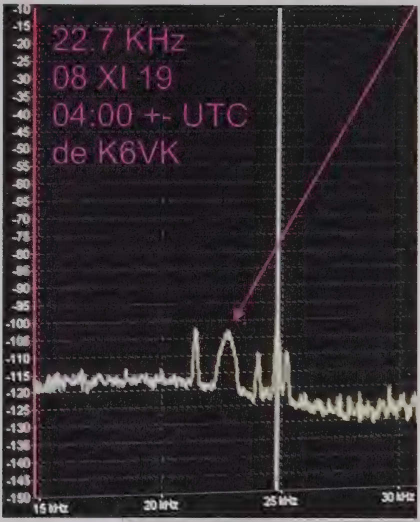


Fig. 43. The mystery signal as first logged at K6VK on November 8, 2019, at 22.7 kHz about 04:00 UTC (local late evening), on the WinRadio G33. (Author's screen cap photo)

Fig. 44. From "The War Zone"— a TACAMO aircraft in flight.

the event of a war, a TACAMO aircraft would be a very safe place to be—for a while.

XII. Long Wave Citizen Science: A Simple and Successful VLF Radio Eclipse Experiment

On August 21, 2017, many radio enthusiasts became Eclipsians, to monitor the effects of the total solar eclipse on radio reception. CHRS radiomen in the VLF interest group, John Staples, John Stuart, Paul Shinn, and the present writer did so. Another total eclipse for North America will happen in 2024.

The U.S. Navy VLF station NML in North Dakota transmits data at 25.2 kHz at high power. Its signal path to California crosses the path of totality shown in Fig. 45. The intersection would occur in the morning at about quarter to eleven, as shown on the map. A simple setup at K6VK produced the results recorded in the graph in Fig. 46.

The signal strength of NML doubled when the path of totality came between the transmitter and the K6VK SDR receiver. Before this intersection, about 1.5 microvolts came down the antenna (the usual daytime strength). At the maximum cross of the paths, that shot up to 3.1 microvolts (about a 6 dB increase); see Fig. 47. That strength then decayed back to normal at about the same rate it had increased.

To record the data, an Apple® iPhone sat in a stable jig, pointed at the screen of the WinRadio® G33 SDR (software-defined radio). Set to time lapse, it recorded about 4 hours of display in 30 seconds of video. The numbers in the graph derive from that video.

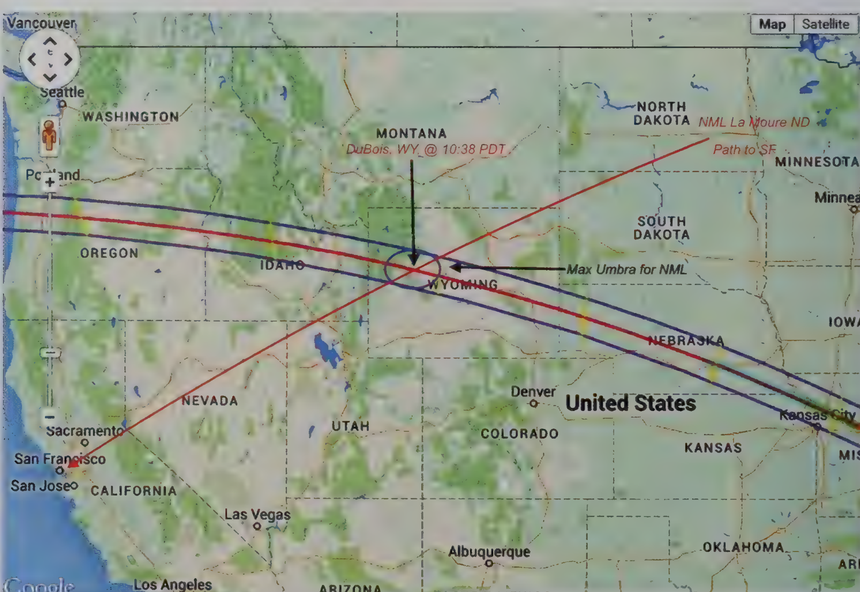


Fig. 45. The 2017 Solar Eclipse and VLF station NML signal at 25.2 kHz path Intersection.

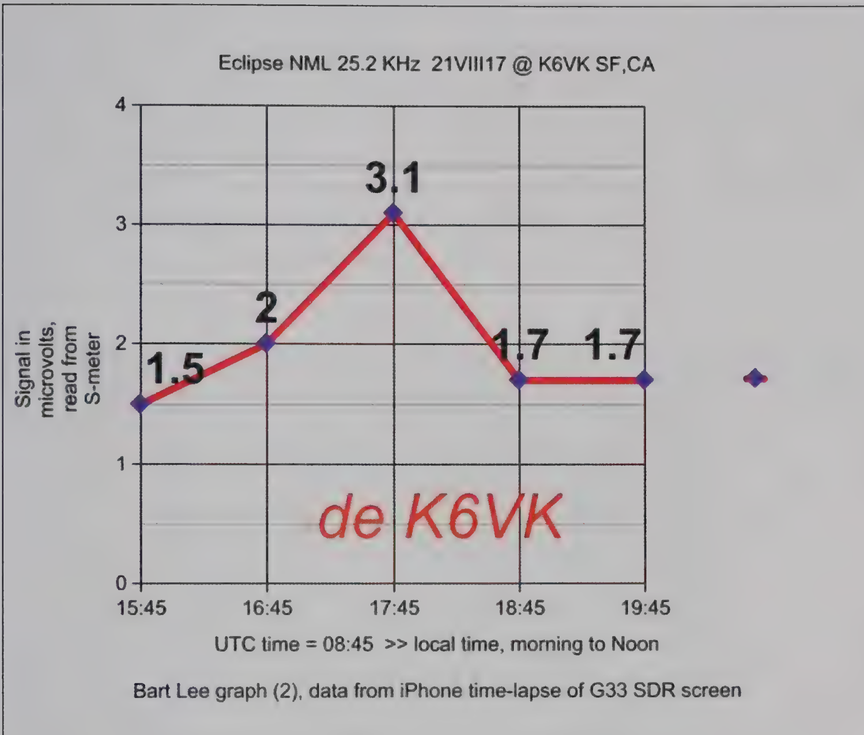


Fig. 46. Graph of increase in VLF station NML (ND) signal strength in California during the eclipse, 6dB+. (Author)

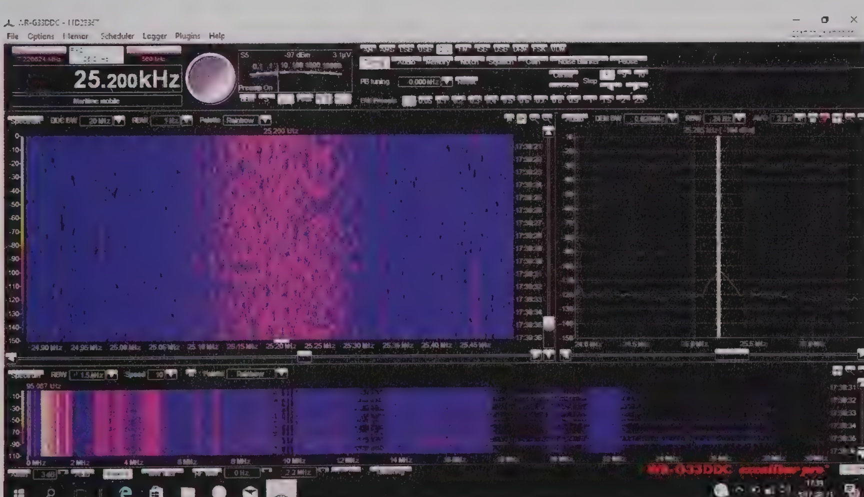


Fig. 47. Maximum signal strength at K6VK at maximum umbra intersection, 3.1 microvolts. (Author's screen cap)

John Stuart also recorded a jump in signal strength for NML, but with more precision. Ionospheric research during the eclipse[21] discovered a "bow-wave" (Fig. 48), which is consistent with the signal strength data for NML as received in San Francisco.

John Staples and John Stuart also recorded WWVB on 60 kHz. Although that signal path was south of totality, major effects appeared. John Stuart observed and recorded these effects on WWVB in the graph in Fig. 49.

Paul Shinn, K6FRC, monitored a long wave beacon some distance away from his home near Lodi, California, both south of totality, and also noted an increase in signal strength. Gilles

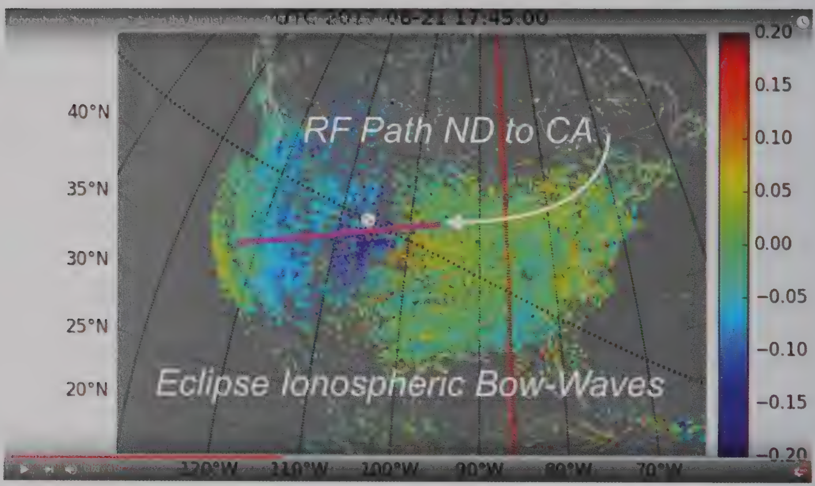


Fig. 48. The ionospheric bow wave (in blue) of the eclipse and the NML signal path. (Source: http://www.skyandtelescope.com/astronomy-news/solar-eclipse-made-bow-waves-earths-atmosphere)

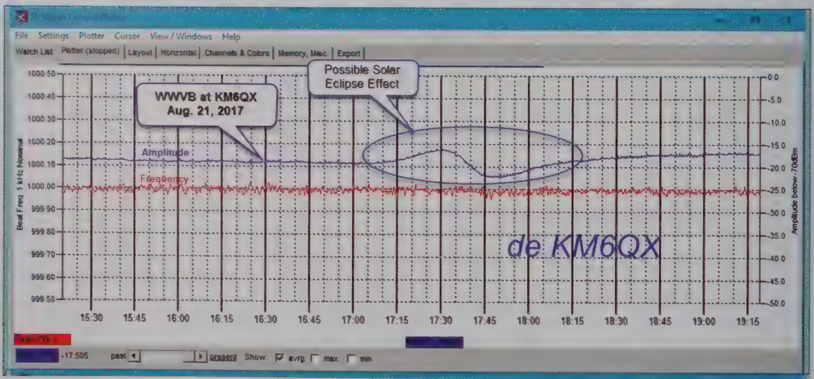


Fig. 49. WWVB at 60 kHz amplitude variation during the eclipse at KM6QX. (John Stuart)

Vrignaud noted that the ARRL's *QST* magazine reported amateur radio experiments during a 1932 eclipse. European amateurs did long wave reception experiments in the 1970s. The consistent result is significant changes in signal strength during an eclipse. The ionized layer high above us, first postulated by Oliver Heaviside in 1902, seems still to be working just fine, even when challenged by a solar eclipse.

XIII. Conclusion: Do It!

Long wave radio is alive and well. All are welcome, as radio receiving stations and even as unlicensed transmitting stations—and, of course, as licensed amateur radio operators. The Cradle of Radio still has much to offer the long wave enthusiast. The Long Wave Club of America would be delighted for you to visit its website, and join up. Join the CHRS VLF Special Interest Group; we'll help you see and hear radio history and today's amazing variety of signals. A wire up a tree, a small homebrew loop antenna, and a PC with a sound card is all it takes. Of course, other aspects of modern technology, such as the SDRs, can make this enthusiasm even more rewarding. Winter nights come every year, and the long wave stations flood the ether. Enjoy!

For the history-minded, Wikipedia is a goldmine of useful information and interpretive analysis. It's usually accurate. Internet searches on topics of interest will yield enormous amounts of reproduced old-time books, journals, and magazines. Many current websites will show and tell you about long wave radio, including YouTube.

Editor's note:
This is an update and expansion of articles previously published in various issues of the *California Historical Radio Society's Journal*. The author expresses his gratitude to the *CHRS Journal* editor, Richard Watts for always going the extra mile.

Endnotes

1. Jack Belrose, Introduction "ELF/VLF/LF Radio Propagation [etc.]," pp. 1–3 (NATO, 1993), http://www.dtic.mil/dtic/tr/fulltext/u2/a267991.pdf.
2. Captain Linwood S. Howeth, USN (Retired), *History of Communications-Electronics in the United States Navy*, 1963, table at http://earlyradiohistory.us/1963hwm.htm.
3. http://www.navy-radio.com/commsta/wailupe.htm.
4. http://www.navy-radio.com/commsta/arlington/NAA-Pages%20from%20Vol3No3-2.pdf.
5. L. A. Gebhard, *Evolution of Naval Radio-Electronics and Contributions of the Naval Research Laboratories* (1979), especially Ch. 3 on VLF. www.dtic.mil/dtic/tr/fulltext/u2/a084225.pdf.
6. J. A. Adcock, VK3ACA, "Propagation of Long Radio Waves," *Amateur Radio* [Australia], June to Sept. 1991, as cited in *QEX*. But cosmic background radiation is very weak, although cosmic rays of high energy are constant. The Adcock article suggests nighttime low-level ionization in the D-layer promotes transmission. During the day, sunlight maximizes D-layer ionization.
7. See: http://www.navcen.uscg.gov/images/Plots/Site_Map_No_CHinch_Lg.jpg.
8. http://www.angelfire.com/mb/amandx/longwave.html.
9. See e.g., http://radiomap.eu/links/.
10. Larry Waldbillig: http://historysdumpster.blogspot.com /2014/11/the-long-wave-radio-band.html, with a recording of its program of ID and weather.
11. http://njdtechnologies.net >> 2016 Field Day.
12. UDXF – UTILITY Dxers FORUM – ELF and VLF Guide Version 1.0 - updated 15 Nov. 2001 WUN - Very Low Frequency Guide - DC to 30 kHz, http://www.udxf.nl/ELF-VLF-GUIDE-v1.0.pdf.
13. https://en.wikipedia.org/wiki/TACAMO.

14. https://fas.org/nuke/guide/usa/c3i/e-6.htm.
15. Kyle Mizokami, "This Unarmed Plane…," *Popular Mechanics*, Apr. 26, 2017.
16. http://nato.radioscanner.ru/frequencies/article107/ (data from participant "Zesty67"). The 17.9 kHz frequency is noted as "active," so maybe that's the Atlantic frequency, and 22.7 kHz the Pacific frequency. The main TACAMO frequencies seem to nest inside the main VLF frequencies.
17. See e.g., http://x264.nl/dump/VLF-Frequencies.txt.
18. Tyler Rogoway, *The War Zone*, Dec. 13, 2019: https://www.thedrive.com/the-war-zone/31477/heres-why-an-e-6b-doomsday-plane-was-flying-tight-circles-off-the-jersey-shore-today.
19. Time to fly home and get a good night's sleep, PST?
20. There is similarly available bandwidth around the 17.9 kHz TACAMO frequency reported as active by the Russian website, above. See Worldwide Very Low Frequency Stations at http://www.smeter.net/stations/vlf-stations.php.
21. Source: http://www.skyandtelescope.com/astronomy-news/solar-eclipse-made-bow-waves-earths-atmosphere/.

About the Author

Bart Lee, K6VK, is a longtime member and Fellow of AWA and a Fellow of the California Historical Radio Society (CHRS), for which he serves as General Counsel Emeritus and Archivist, and as one of several historians. He holds the FCC General Radio Operators License (with the RADAR endorsement) and an amateur radio extra class license. He has enjoyed radio and radio-related activities in many parts of the world and a fair amount of time on the high seas. Radio technology has fascinated him since he made his first crystal set with a razor blade and pencil lead some 65 years ago. He is especially fond of those sets of which it is said: "Real radios glow in the dark."

Bart is a published author on legal and other subjects, and extensively on the history of radio. The AWA presented its Houck Award for documentation to him in 2002, and CHRS presented its 1991 "Doc" Herrold Award to him in connection with his work for the Perham Foundation Electronics Museum, which declared him an Honorary Curator and Historian. In 2001, during disaster recovery operations in New York after the 9/11 terrorist enormity, he served as the Red Cross deputy communications lead from September 12 to September 21 (in old radio talk, the "night shift trick-chief"). Bart is a retired litigator by trade, having prosecuted and defended civil cases in federal and state courts for 40 years. He is a graduate of St. John's College (the "Great Books School") and the University of Chicago Law School (on the faculty of which he served after graduation).

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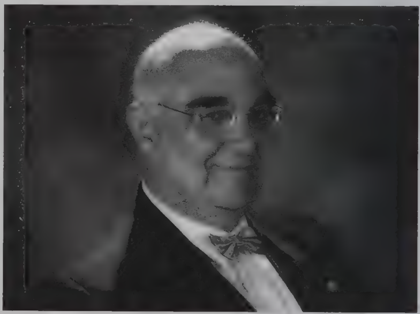
Bart invites correspondence at email KV6LEE@gmail.com.



Bart Lee (Photo by Paula Carmody in Indonesia.)

Letter to the Editor

Re: Telegraph Wars: Mormons, Native Americans, and the Transcontinental Telegraph

Dear Mr. and Ms. Bart,

You folks not only put together a fine history of the construction of the telegraph across the USA but a most fascinating description of how the Native Americans interfaced with the "invading forces!" Thanks so much.

Richard Brewster, Cutchogue, NY

Letter to the Editor

Re: History of FM Radio: 1940s to 1960s

Dear Michael,

Just finished reading your fine article. So very detailed and interesting…and I, a fine music enthusiast from the early 1950s, remembered those times well. If you listened to FM in those days, you were automatically considered someone who just liked classical music. And all the major NYC stations played great music on their FM outlets without commercials…wow! Finally got an FM radio in my car in the early 1960s. It was a big deal…built a separate amplifier to feed the rear seat speaker! I even installed a horizontal loop antenna to improve reception. So sad about Armstrong.

Best Regards, Richard Brewster, Cutchogue, NY

Letter to the Editor

Re: Book in General

Dear Editor Martin:

I have just finished reading the *AWA Review* that I received last week. Thank you for your work in its production. Each article was of some interest, but the kits, FM history, and the industrial design articles are of particular interest for me. Thank you for your excellent selection on a variety of subjects.

Andy Ooms, Spring Valley, CA

Letter to the Editor

Re: Book in General

Tim, I very much enjoyed the 34^{th} (2021) edition of the *AWA Review*. It is clear that a ton of hard work by the authors and editorial and production staffs was put into it.

Keith Kunde, Independence, OH

Letter to the Editor

Re: History of FM Radio

Dear *AWA Review* Editor:

I recently received my copy of Volume 34 of the *AWA Review.* As usual, it is an outstanding volume which I found to be of great interest. However, in going through the papers within, I believe there is a significant error in the caption to Figure 31 of the "History of FM Radio" article. In particular, I feel that the caption sentence that reads, "Also shown at left is the dual speaker control to bring music to your back seat passengers." is incorrect. The problem is that the box to the left of the picture is actually the power supply module that provides B+ for the tube circuits.

I say this for two reasons:

1) Author Mike Molnar takes Figure 31 of this article from Figure 2 of the article he references on page 75 of Vol. 28. The caption on that picture makes no mention of the power supply or the speaker fader/balance control. (The FM-900 is a mono-only radio, but it is designed to drive two speakers.) Figure 4 of the Vol. 28 article shows the power supply module interior, and Figure 13 contains the schematic of the FM-900. The lower right corner of Figure 13 shows the speaker fader/balance circuitry and connections.

2) I own a FM-900, and have done so since 1968.

My FM-900 has more than 200,000 miles on it in two vehicles. It has all of its original tubes and transistors. It is in regular use on my shop workbench, where it is powered by the shop 13.6 volt power supply. Performance is very good, as I have the radio connected to my external FM antenna. The attached Fig. 1, Fig. 2, Fig. 3, and Fig. 4 show how the radio is mounted beneath a shelf (spacers not visible), along with details of the front panel, power supply mount, and connections for antenna and speakers.

In no way do I consider this caption error to be a major problem with Mr. Molnar's wonderful paper, but I do feel that any FM-900 aficionado might get a bit confused when seeing that caption on Figure 4 of the current article. Thank you for an excellent publication.

Regards, Dale Svetanoff, WA9ENA, Monticello, IA

(Editor's note: Dale Svetanoff is indeed correct.)

Fig. 1. (Right) Mounting of Motorola FM-900 beneath shelf that supports a Tektronics scope.

Fig. 2. Front panel detail of the FM-900. Controls are (L to R): On/Off Volume, Tone, Speaker Fader/Balance, Tuning.

Fig. 3. Separate power supply chassis mounted to bench shelf rise.

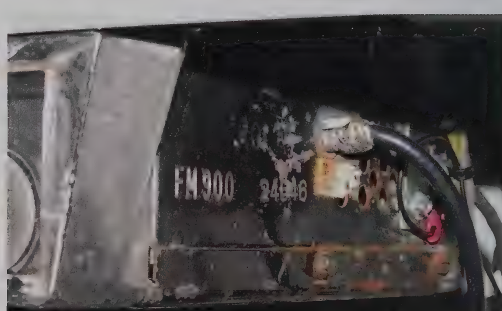


Fig. 4. Side view of FM-900 showing the antenna jack and the speaker connection.

Re: History of FM Radio (continued)

Tim,

Thanks for the prompt reply. I hope you saw the pictures and captions I attached to the message, as the caption for the picture labeled as Fig. 2 provides the full description for each control. The "speaker/fader balance" control does just that. It is not separate from the radio: it is on the front panel of the radio (small knob nearest the main tuning knob). The reason I say "fader/balance" is that the function of said control changes as to whether there are 2 speakers or just 1 speaker connected. When only 1 speaker is in use, the control does little; but when 2 speakers are properly connected, the control varies the level at the speakers, thus setting the balance between them. (Some would call that a "fader" action.)

So, again, there are NO other items involved in an installed FM-900 other than 1 or 2 speakers. The power supply module is just that. All controls are on the front panel of the radio itself and the power supply mounts nearby. The wires/cables that connect to the FM-900 are power, 1 or 2 speaker cables, and the antenna coax.

I don't know if you plan to send my message to Mike Molnar or not, but I am thinking he might like to know about the error. In any case, thanks for an excellent volume.

Regards, Dale Svetanoff, WA9ENA, Monticello, IA

Letter to the Editor

Re: History of Kits

Hello Tim,

Thank you so much for sending a copy of the *AWA Review* Vol. 34, 2021. What a delightful surprise it was to turn to page 35 where I saw the Philmore NT200 transmitter. I built it as a kit in 1963 but later added a cabinet, a meter (in lieu of a #47 lamp for tuning), and an antenna changeover relay. It served me well until being replaced by a Heathkit Apache transmitter in 1974. It's amazing how many contacts I made with this thing with only 15 watts of power.

The drug store tube tester on page 43 also brought back memories of the days when I was learning how to fix my parent's TV set.

Regards, Jerry Proc, VE3FAB, Etobicoke, Ontario, Canada

Letter to the Editor

Re: Book in General

Mr. Martin,

Congratulations on Vol. 34 of the *AWA Review*. It is a fine piece of scholarship. It reflects great credit upon you and the AWA.

Cordially, Neil D. Friedman, N3DF, Dayton, OH

Letter to the Editor

Re: KDKA

Hi,

I would like to contact David and Julia Bart about their excellent article on KDKA in the 2020 *AWA Review.*

Thanks, Jerry Berg, Lexington, MA

Letter to the Editor

Re: Oliver Lodge's Contribution to the Discovery of Electromagnetic Waves

Hi Eric,

I've started reading your AWA article on Lodge, and was impressed once again with how thoroughly you research your topics. As you've noted, much that has been written about radio and electricity's pioneers is repeated misinformation… telephones… it goes on and on. Have you considered writing your own book? "Electricity and Radio: Who really invented what?" Such a book would fill an enormous void and reach the wider audience the subject deserves. While a huge undertaking, you've already done much of the research, and I think only you could write it.

Best regards, Gary Gordon, Saratoga, CA

Letter to the Editor

Re: Oliver Lodge's Contribution to the Discovery of Electromagnetic Waves

Hi Eric:

Your piece in the latest *Review* is really impressive. On the whole, it's a good issue.

A. David Wunsch, Belmont, MA

Letter to the Editor

Re: Oliver Lodge's Contribution to the Discovery of Electromagnetic Waves

Eric, just read your article, outstanding and very educational. Much learned. Keep up the good work.

C. E. "Sonny" Clutter, aka; the Radiola Guy, Camas, WA

Letter to the Editor

Re: Oliver Lodge's Contribution to the Discovery of Electromagnetic Waves

Dear *AWA Review* Editor:

There appears to be a typo in the Wenaas article in Vol. 34 of the *Review*. At least I think it is a typo—or maybe "back in the day" the letter "k" meant 1E6 and not 1E3. Anyhow on page 286 and again on page 323, when referring to H. Hertz's calculations of "wave speed," the velocity calculation drops a factor of 1000 in the final number, viz., it is listed at 200 or 280 km/s instead of 200,000 or 280,000 km/sec. A picky point to be sure—and maybe easily explained—but it sure stopped me in my tracks for a bit. Would you please pass this along to Dr. Wenaas? At one time I had his email but have lost it. Other than that little stopper, I have enjoyed the latest *Review* immensely. Always a good read with its mix of entertaining and scholarly articles. I have all of the volumes on a special shelf in my radio shop.

Many thanks, John Foell, Life Member of AWA, Auburn, IN

(Editor's note: John Foell is indeed correct.)

Letter to the Editor

Re: History of Kits and Oliver Lodge's Contribution to the Discovery of Electromagnetic Waves

Greetings *AWA Review* Editor:

I really enjoyed the latest *Review*, especially the Chuck Penson article on kits; being a Heathkit builder of a few, with the DX-100 being the first, then many others. I didn't realize all the other kits from back when.

I do have a question or four regarding the Eric Wenaas article on Oliver Lodge. On page 283, Figure 3, item J, is that an iron core wrapped with insulated wire? Same with page 295, Figure 10, item A; same as item J above? How does the Hertz dipole oscillator get excited to work? Magnet?

Thank you, great *Review*, I appreciate your efforts!

Sincerely, Dennis R. Murphy, K0GRM, Bismarck, ND

Re: Oliver Lodge's Contribution to the Discovery of Electromagnetic Waves (continued)

Author response.

Referring to Fig. 5, Dennis asked, "How was the Hertz Dipole Oscillator excited to work?" This figure and ones similar to it appeared in many of Hertz's writings. In these figures, Hertz used the simple drawing denoted with an "A" in Fig. 5 to represent the source of excitation for his oscillators. The details of this source are not obvious from the drawing.

The short answer to the question asked is that the apparatus denoted by "A" is actually a Ruhmkorff coil, an example of which is shown in Fig. 6.[1] The knobs at "G" in Fig. 6 are the same as the knobs on the drawing labeled "A" in Hertz's representation of his oscillator reproduced in Fig. 5. A Ruhmkorff coil is a simple induction coil with an interrupter attached to one end that will produce a repetitive train of high-voltage pulses at "G." For those who know how a Ruhmkorff coil works, no further explanation is needed. For those who do not, a brief explanation follows.

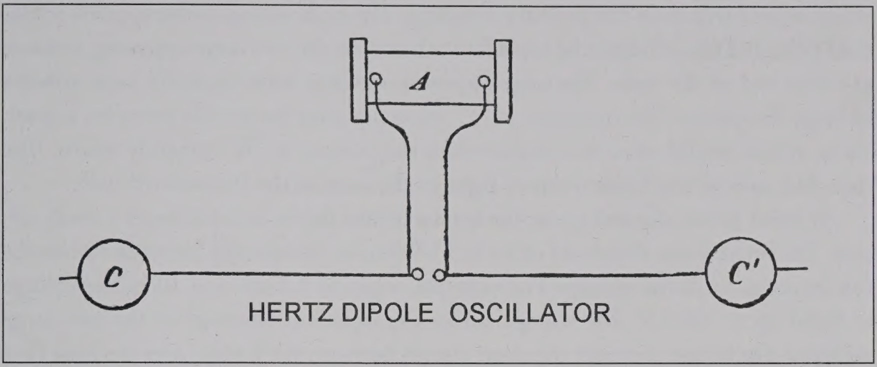


Fig. 5. Hertz's representation of his Hertz oscillator.

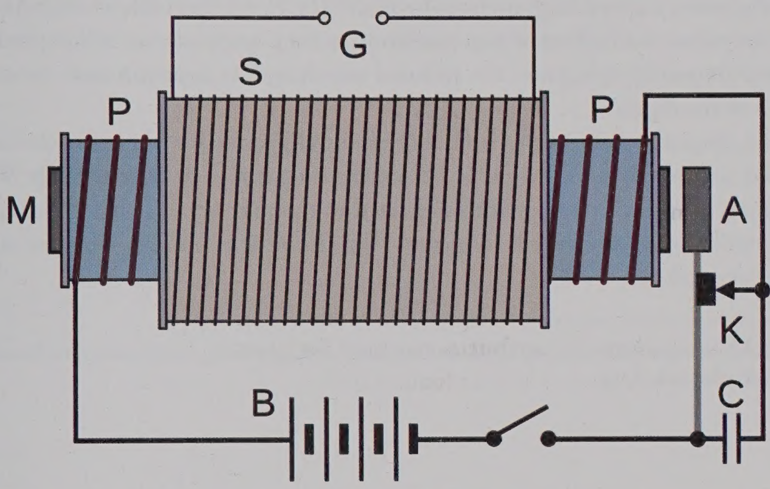


Fig. 6. A simplified diagram of a Ruhmkorff coil.

When the switch at the battery "B" is closed, the current builds up in the primary "P" of the induction coil with time a time constant $\tau = L/R$ where R is the primary winding resistance and L is the primary winding inductance. The voltage in the primary builds up relatively slowly, and the magnetic field produced in the iron core "M" also builds up equally slowly. At some point, the force produced by the magnetic field on the iron button "A" attached to the contact arm is greater than the force of a spring (not shown) that works to keep the contact closed.

At the point when the force from the magnetic field is greater than the opposing force from the spring, the contact "K" opens up, causing the current flowing in the primary coil to abruptly stop. The large rate of change of current in the primary circuit induces a very large voltage pulse in the secondary winding "S," which has

many more turns than the primary winding. The high voltage pulse appears across the knobs and also charges the capacitance between the two large opposing surfaces at either end of the rods. The large opposing surfaces were typically large spheres or large flat plates. The capacitor at "C" placed across the switch prevents a spark there, which would otherwise occur when the contact at "K" abruptly opens. The capacitor is typically hidden out of sight in the base of the Ruhmkorff coil.

At some point, the voltage at the knobs breaks down and produces a short circuit. The breakdown threshold of air is 3 MV/m, so the spacing between the knobs can be set to limit the voltage. For example, a gap of 3.3 cm will allow the voltage to build up to 100 kV. The voltage across the capacitor (formed by the two large surfaces) discharges through the short circuit between the knobs, and the rods ring down and lose energy by radiating electromagnetic energy at or near the resonant frequency of the LC circuit formed by the inductance of the rods and the capacitance between the two large surfaces $f = 1/[2\pi\sqrt{(LC)}]$. An ideal dipole antenna at or near resonance is a half-wavelength radiator, so for a spark source, which produces a broad frequency spectrum, the radiated wavelength is approximately twice the length of the dipole.

The magnetic field in the iron core essentially vanishes when the contact K opened, and without the magnetic field, the spring is able to close the gap. When the gap is closed, the battery is reconnected to the primary, and the cycle repeats itself until the battery switch is opened. The circuit is essentially a buzzer with a secondary coil.

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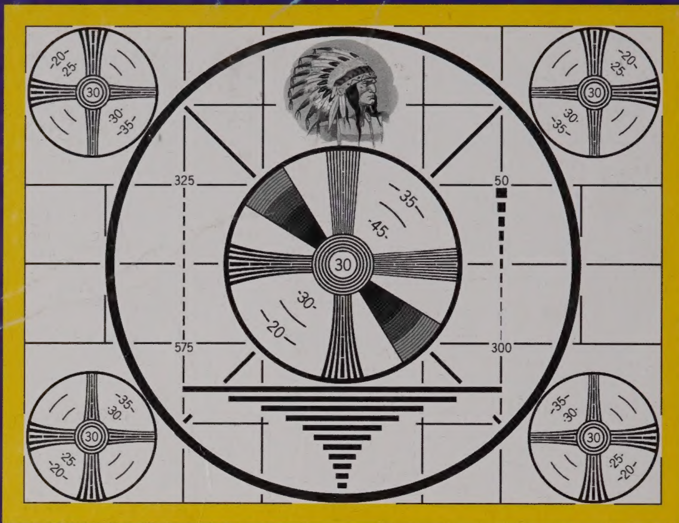
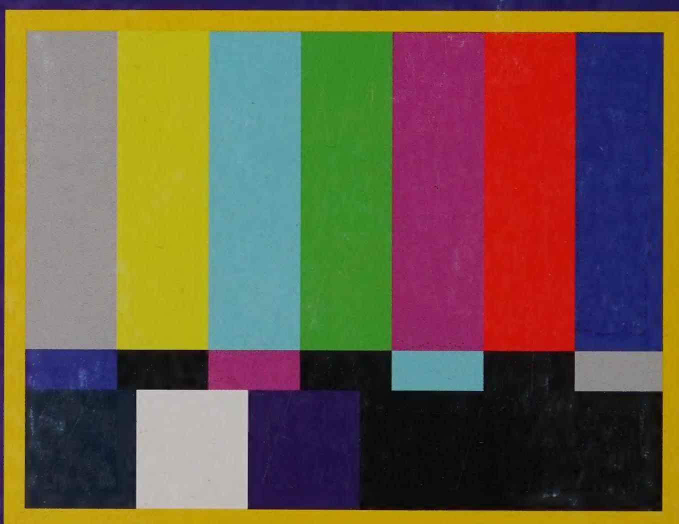
1. https://commons.wikimedia.org/wiki/File:Ruhmkorff_coil_schematic_1.svg#/media/File:Ruhmkorff_coil_schematic_1.svg





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